Chapter 3
Volcanic facies architecture of the Mount Black and Sterling Valley Volcanics

3.1 Introduction

This chapter focuses on the volcanic lithofacies and facies architecture of the Mount Black and Sterling Valley Volcanics. The identification of facies and their genetic interpretation are based on detailed textural observations of field exposures, drill core, polished hand samples and thinsections. Identification of volcanic facies in the Mount Black and Sterling Valley Volcanics is challenging as they are generally laterally discontinuous and texturally heterogeneous. In addition, post-depositional diagenesis, hydrothermal alteration, deformation and metamorphism have modified primary textures and mineralogies. Despite this, 28 distinct volcanic and sedimentary facies have been identified and given descriptive names that reflect their primary mineralogy, texture and composition.

Phenocryst assemblages were used to discriminate among different coherent lithofacies and as a guide to the primary composition of both coherent and volcaniclastic facies. Different phenocryst assemblages have been correlated with geochemical compositions based on immobile element ratios (Chapter 4). The majority of felsic facies are feldspar-phyric only, some rhyolite is quartz-feldspar-phyric, and some dacite is feldspar-hornblende-phyric. The mafic facies are feldspar-phyric, aphyric or feldspar-clinopyroxene-hornblende-phyric.

Spatially, texturally, mineralogically and compositionally related coherent and volcaniclastic facies are assigned to several facies associations. These facies associations include: (1) rhyolite facies association which comprises coherent rhyolite, monomictic rhyolite breccia and rhyolite mixed breccia; (2) quartz-feldspar-phyric rhyolite facies association which consists of quartz-feldspar-phyric rhyolite and quartz-feldspar-phyric rhyolite-siltstone breccia; (3) dacite facies association consisting of coherent feldspar-phyric dacite, monomictic dacite breccia and dacite mixed breccia; (4) feldspar-hornblende-phyric dacite facies association which includes coherent feldspar-hornblende-phyric dacite and monomictic feldspar-hornblende-phyric dacite breccia; (5) mafic facies association which comprises feldspar-phyric andesite and basalt, aphyric andesite and basalt, monomictic mafic breccia and mafic mixed breccia.

These rhyolitic to basaltic facies associations are hosted in volcaniclastic and sedimentary facies. In the Mount Black Volcanics, the enclosing facies include: pumice-rich facies association (pumice breccia, pumice-rich sandstone and shard-rich siltstone), pumice-lithic clast-rich facies association (pumice-lithic clast-rich breccia and sandstone), crystal-rich sandstone, black mudstone and carbonate facies association (banded carbonate, carbonate-volcanic breccia and carbonate-matrix breccia). The host succession to the Sterling Valley Volcanics includes: polymictic volcanic facies association (polymictic mafic breccia, mafic volcanic sandstone and siltstone) and black mudstone.

Massive basalts and dolerites have intruded the Mount Black and Sterling Valley Volcanics.

The characteristics of the facies and their associations in the Mount Black and Sterling Valley Volcanics are described in sections 3.3 to 3.1 and Table 3.1. The distribution of the facies are summarised in the map (Fig. 3.1) and cross sections (Figs. 3.2 and 3.3). The physical processes of eruption, transport and emplacement are interpreted from volcanic and sedimentary textures and structures. The provenance and environment of deposition are discussed in section 3.15. Finally, this chapter attempts to reconstruct the facies architecture of the Mount Black and the Sterling Valley Volcanics prior to deformation (section 3.16).

3.2 Terminology

In this study the following terms are defined as:

A *facies* is any interval of rock or sediment that exhibits field, handspecimen or thinsection characteristics significantly different from other intervals of rock or sediment (Selley, 1976, Middleton, 1978, Walker, 1984). A particular facies may occur many times within the succession.

A *facies association* is a collection of facies that are spatial, mineralogically, compositionally or texturally related and may also be genetically related (Cas and Wright, 1987).

The *facies architecture* is the way in which single units are positioned in time and space (Allen and Allen, 1990a).

Fiamme are lenticular, juvenile volcanic fragments, which define a pre-tectonic foliation (McPhie et al., 1993). They can occur in both welded pyroclastic deposits (Smith, 1960; Ross and Smith, 1961) and non-welded pumice-rich deposits (Allen, 1988, 1990a unpub.; Allen and Cas, 1990 unpub.; Branney and Sparks, 1990). Here the term "fiamme" is used to describe a texture within the rock and not to imply a particular origin (Chapter 6).

Pyroclasts are fragments (pumice, scoria, shards, crystals and lithic fragments) produced by explosive eruptions (Fisher, 1960, 1966).

Syn-eruptive facies are those which are genetically related to active volcanism and comprise clasts that were produced by volcanic processes, but were deposited by sedimentary processes (McPhie et al., 1993). Syn-eruptive resedimentation can occur where clasts bypass initial deposition as primary pyroclastic or autoclastic deposits and are delivered directly to sedimentary transport and deposition systems (McPhie et al., 1993). Alternatively, they may result from rapid redeposition during or immediately after eruption. Unlike post-eruptive facies, syn-eruptive facies comprise texturally unmodified clasts of uniform composition and clast type, and are not intercalated with other facies.

3.3 Rhyolite facies association

The rhyolite facies association consists of three spatially related facies: coherent rhyolite, monomictic rhyolite breccia and rhyolite mixed breccia facies.

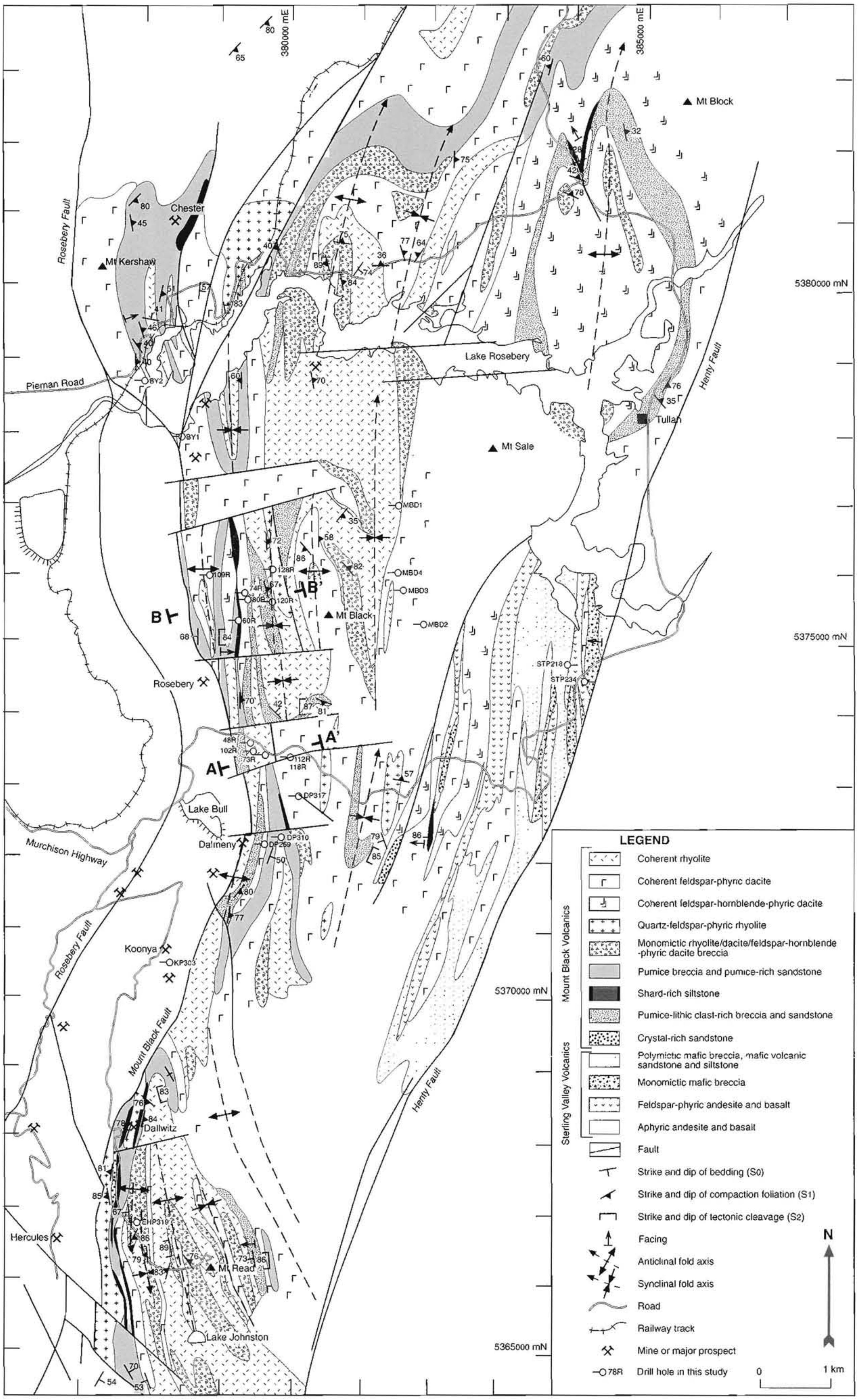


Figure 3.1: Simplified geological map showing the distribution of the main facies in the Mount Black and Sterling Valley Volcanics. Geology mapped by C Gifkins.

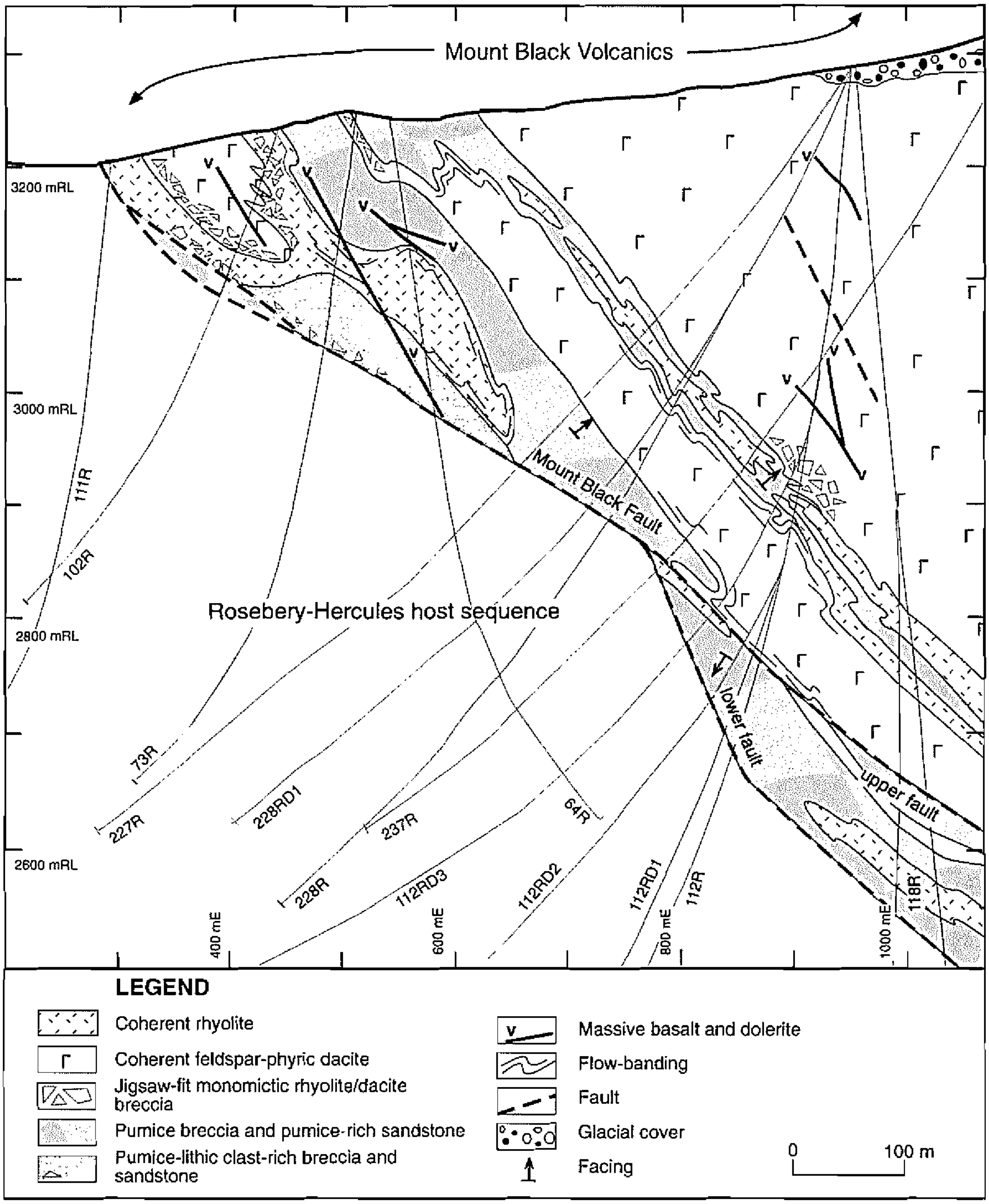


Figure 3.2: Simplified geological cross section located at 900 m south mine grid, Rosebery. The section line is marked on Figure 3.1, A-A'. This section shows the distribution of facies in the Mount Black Volcanics adjacent to the Mount Black Fault.

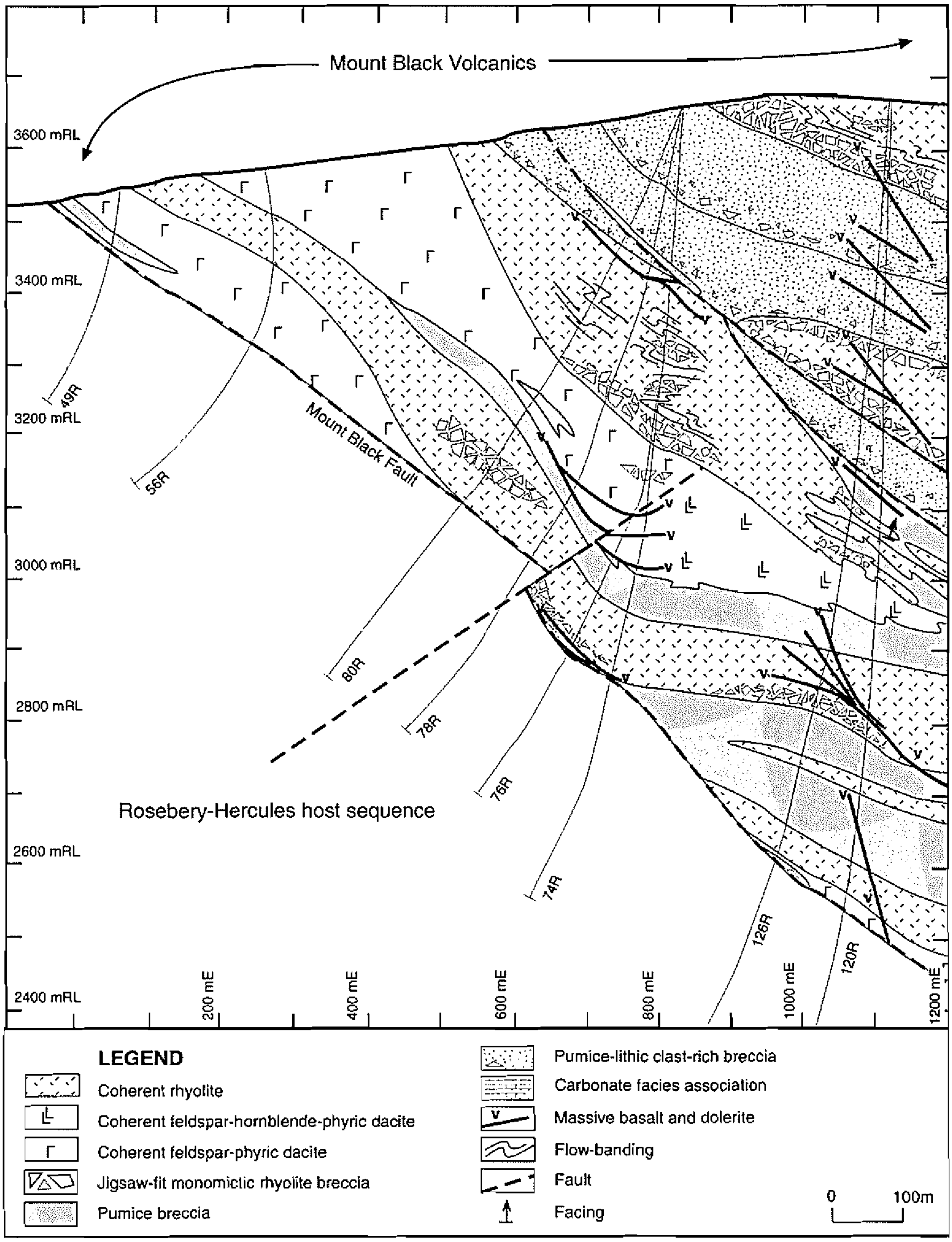


Figure 3.3: Simplified geological cross section, through the Mount Black Volcanics, located at 1320 m north mine grid, Rosebery. The section line is marked on Figure 3.1, B-B'.

Table 3.1: Characteristics of facies in the Mount Black and Sterling Valley Volcanics. fld= feldspar, qtz= quartz, hbl= hornblende, px= pyroxene, musc=muscovite.

Facies	*Lithofacies characteristics*	*Thickness x lateral extent*	*Mineralogy/ Components*	*Textures*	*Associated facies*	*Interpretation*
Coherent rhyolite	massive, flow-banded or brecciated	1-100 m x 0.5-2 km	3-10% fld, phenocrysts	porphyritic and glomeroporphyritic; perlitic, amygdaloidal, pumiceous, spherulitic or micropoikilitic	monomictic rhyolite breccia and rhyolite mixed breccia	coherent facies of lavas, domes, cryptodomes and syn-volcanic sills
Monomictic rhyolite breccia (jigsaw-fit, clast-rotated, blocky, flow-banded and graded or stratified rhyolite breccia)	massive; poorly sorted; clast- or matrix-supported; jigsaw-fit and clast-rotated textures; sparse normally graded or diffusely stratified units	2-60 m x <0.1-1 km	0-20% fld-phyric rhyolite clasts	blocky clasts with planar and curviplanar margins; clasts are non-vesicular to pumiceous, massive or flow-banded, perlitic or microspherulitic	coherent rhyolite, rhyolite mixed breccia, pumice-lithic clast-rich breccia	in situ, clast-rotated and resedimented hyaloclastite and autobreccia
Rhyolite mixed breccia	massive; gradational contacts; poorly sorted; domains of jigsaw-fit clasts; clast- to matrix-supported	10 cm–20 m x < 50 m	0-30% fld-phyric rhyolite and pumice or pumice-lithic clast-rich breccia, sandstone or siltstone clasts		coherent rhyolite and monomictic rhyolite breccia	peperite
Quartz-feldspar-phyric rhyolite	massive, sparse flow-banding	200 m x <1.5 km	5-15% fld> qtz phenocrysts	densely microspherulitic or micropoikilitic	quartz-feldspar-phyric rhyolite-siltstone breccia	syn-volcanic dyke
Quartz-feldspar-phyric rhyolite-siltstone breccia	massive	2 x 10 m	5-10% fld-qtz-phyric rhyolite and silicified siltstone clasts		quartz-feldspar-phyric rhyolite	peperite
Coherent feldspar-phyric dacite	massive, sparse flow-banded or brecciated margins	10-300 m x <2 km	5-25% fld phenocrysts	porhyritic and glomeroporphyritic; perlitic, vesicular; microspherulitic or micropoikilitic	monomictic dacite breccia and dacite mixed breccia	coherent facies of lavas, domes, cryptodomes and syn-volcanic sills
Monomictic dacite breccia	normally graded or diffusely stratified; poorly sorted; clast- or matrix-supported; massive, jigsaw-fit and clast-rotated textures	2-60 m x <100 m	5-25% fld-phyric dacite clasts	blocky clasts with planar and curviplanar margins; clasts are non-vesicular or vesicular, massive or flow-banded, perlitic or microspherulitic	coherent fld-phyric dacite and dacite mixed breccia	in situ, clast-rotated and resedimented hyaloclastite and autobreccia
Dacite mixed breccia	massive; gradational contacts; domains of jigsaw-fit clasts	0.1-20 m x <50 m	5-25% fld-phyric dacite and pumice or pumice-lithic clast-rich breccia, sandstone or siltstone		coherent fld-phyric dacite, monomictic dacite breccia	peperite

Table 3.1 continued: Characteristics of facies in the Mount Black and Sterling Valley Volcanics. fld= feldspar, qtz= quartz, hbl= hornblende, px= pyroxene, musc= muscovite.

Facies	*Lithofacies characteristics*	*Thickness x lateral extent*	*Mineralogy/ Components*	*Textures*	*Associated facies*	*Interpretation*
Coherent feldspar-hornblende-phyric dacite	massive; locally flow-banded and brecciated; flow-aligned phenocrysts	100-800 m x <2 km	7-15% fld, 3-5% hbl, 1% qtz phenocrysts	porphyritic and glomero-; perlitic or micropoikilitic or microspherulitic	monomictic fld-hbl-phyric dacite breccia	coherent facies of lava domes or cryptodomes
Monomictic feldspar-hornblende-phyric dacite breccia	massive; poorly sorted; clast- or matrix-supported; jigsaw-fit and clast-rotated textures	200 m x <100 m	10-20% fld>hbl-phyric dacite clasts	perlitic, blocky clasts with planar and curviplanar margins	coherent fld-hbl-phyric dacite	in situ and clast-rotated hyaloclastite
Feldspar-phyric andesite and basalt	massive and brecciated with perlitic margins	2-50 m x ?	3-10% fld, hbl, px phenocrysts	massive or perlitic; amygdaloidal	monomictic mafic breccia and mafic mixed breccia	coherent facies of lavas and syn-volcanic sills
Aphyric andesite and basalt	massive, fine-grained	<10 m x ?		aphanitic		coherent facies of lavas and sills
Monomictic mafic breccia	massive or graded; poorly sorted; clast-supported; jigsaw-fit and clast-rotated	<20 m x ?	2-25% fld-phyric andesite or basalt clasts	angular, blocky clasts with planar and curviplanar margins	massive fld-phyric andesite or basalt and mafic mixed breccia	in situ, clast-rotated and resedimented hyaloclastite
Mafic mixed breccia	massive; gradational contacts; domains of jigsaw-fit clasts	<1 m x <10 m	siltstone and fld-phyric andesite or basalt	elongate, ragged siltstone clasts surrounded by andesite or basalt	fld-phyric andesite or basalt and monomictic mafic breccia	peperite
Pumice breccia	thick, massive or normally graded or diffusely stratified pumice-rich sandstone or shard-rich siltstone tops and lithic clast-rich bases	<100 m x 16 km	fld-phyric tube pumice clasts, shards and fld-phyric (3-20%) lithic clasts	compacted and uncompacted pumice clasts, fiamme, bedding-parallel stylolites	pumice-rich sandstone and shard-rich siltstone	pyroclasts from a large submarine explosive eruption deposited by syn-eruptive high-concentration gravity flows
Pumice-rich sandstone	massive, normally or reversely graded or diffusely stratified; well sorted; clast-supported; erosional bases	2 m x 100's m	tube pumice clasts, fld crystal fragments, shards	compacted and uncompacted pumice clasts, fiamme, bedding-parallel stylolites	pumice breccia and shard-rich siltstone	pyroclasts deposited by syn-eruptive density currents or water-settled fall, sourced either directly from submarine eruption/s or pre-existing deposits
Shard-rich siltstone	diffusely laminated, graded or cross-laminated; well sorted	1.5 cm –2 m x ?	shards and fld crystal fragments	fiamme, outsized flattened fld-phyric pumice clasts	pumice breccia and pumice-rich sandstone	syn-eruptive deposition and resedimentation of ash by low-density turbitidy currents and water-settled fall
Pumice-lithic clast-rich breccia	massive and normally graded; erosional lower contacts	20-250 m x 100-1500 m, single beds 2-80 m thick	fld crystal fragments, tube pumice and fld-phyric rhyolite and dacite clasts	massive or flow-banded, perlitic or spherulitic rhyolite or dacite and pumice clasts; fiamme	coherent rhyolite and pumice-lithic clast-rich sandstone	hyaloclastite, autobreccia and/or pumice breccia resedimented by syn-eruptive gravity flows

Table 3.1 continued: Characteristics of facies in the Mount Black and Sterling Valley Volcanics. fld= feldspar, qtz= quartz, hbl= hornblende, px= pyroxene, musc=muscovite.

Facies	*Lithofacies characteristics*	*Thickness x lateral extent*	*Mineralogy/ Components*	*Textures*	*Associated facies*	*Interpretation*
Pumice-lithic clast-rich sandstone	lenses and channels; massive or normally graded; convolute or diffusely laminated	1 m x 1-100 m	fld crystal fragments, pumice, rhyolite and dacite clasts	fiamme	pumice-lithic clast-rich breccia	hyaloclastite, autobreccia and/or pumice breccia resedimented by syn-eruptive high-concentration density currents
Crystal-rich sandstone	massive, tabular beds with sharp planar bases; well sorted; clast-supported	4 m x ~ 2 km	20% fld, 10-40% qtz, <1% musc, 1% zircon, 5-10% oxide crystal fragments, gabbro, basalt, dacite, pumice, chert and meta-siltstone clasts			mixed provenance including Precambrian basement and the Mount Read Volcanics; deposited from post-eruptive high-concentration turbidity currents or sandy debris flows
Polymictic mafic breccia	poorly sorted; clast-supported; massive to graded with diffusely stratified siltstone tops	4-80 m x 100's m	5-20% fld± hbl± px crystal fragments, andesite, dacite, basalt and scoria clasts	blocky, angular dacite to basalt clasts with planar and curviplanar margins; ragged scoria clasts.	mafic volcanic sandstone and siltstone	hyaloclastite, autobreccia and /or pyroclastic scoria resedimented by syn-eruptive debris flow or grain-flow
Mafic volcanic sandstone	diffusely laminated; normal and reverse graded; interbedded with mafic volcanic siltstone	20-40m x 100's m, single beds 0.2-2m thick	10% fld crystal fragments, volcanic lithic clasts		polymictic mafic breccia and mafic volcanic siltstone	hyaloclastite and autobreccia resedimented by syn-eruptive high-concentration turbidity currents
Mafic volcanic siltstone	diffusely laminated	5 x 100's m, single beds mm's thick	chlorite, musc, magnetite, hematite and fld		polymictic mafic breccia and mafic volcanic sandstone	deposited by syn-eruptive high-concentration turbidity currents
Black mudstone	massive and laminated	1 x 50 m, 0.5 -2 mm thick laminations	polycrystalline quartz, mica and pyrite (1%)			hemi-pelagic and non-pelagic mudstone
Massive basalt and dolerite	massive; discordant contacts	0.1-3 m x 100 m	<3% fld porphyritic	Amygdaloidal; moderately well-developed S_2 cleavage		post-lithification dykes (Henty Dyke Swarm)
Banded carbonate	foliated; planar or folded bands	2 m x 3km?	calcite	stylolitic foliation	carbonate-volcanic breccia and carbonate-matrix breccia	carbonate-altered volcanic facies or limestone?
Carbonate-volcanic breccia	massive	4 cm – 35 m x 3 km?	fld-phyric volcanic and carbonate clasts; rare pumice clasts		banded carbonate and carbonate-matrix breccia	carbonate-altered monomictic rhyolite breccia and pumice-lithic clast-rich breccia
Carbonate-matrix breccia	massive; gradational contacts	1 m x ?	fld-phyric clasts in calcite-rich matrix		carbonate-volcanic breccia and banded carbonate	carbonate-altered peperite?

3.3.1 Coherent rhyolite

Coherent rhyolite is common in the western and northern part of the Mount Black Volcanics, at Mount Read, Rosebery, along the Pieman Road, Pinnacles and north of Mount Block (Fig. 3.1). Intervals of coherent rhyolite form discontinuous lenses that vary in thickness from 1 m to 100's m and have lateral extents between 500 m and 2 km (Figs. 3.2, 3.3 and 3.4). Coherent rhyolite is typically massive, flow-banded, or brecciated and may have vesicular or pumiceous margins (Fig. 3.4 and Chapter 5). Intervals of in situ monomictic rhyolite breccia or inclusions of siltstone (Fig. 3.4) mark contacts. Thick intervals of monomictic rhyolite breccia are also commonly associated with the margins of coherent rhyolite units (Figs. 3.4 and 3.5). In some drill core intersections, intervals of massive, flow-banded and brecciated rhyolite are complexly intercalated (Fig. 3.4).

This facies is characterised by 3-10%, evenly distributed, euhedral, 1-2 mm plagioclase phenocrysts in a fine-grained groundmass of feldspar-quartz-sericite ± chlorite ± calcite (Fig. 3.4D). Plagioclase phenocrysts are variably altered to albite, sericite, calcite, chlorite, epidote and polycrystalline quartz (Fig. 3.6B).

Flow-banding commonly occurs near the margins of units (Figs. 3.4, 3.5 and 3.6A) and is convolutely folded. Flow-banding is defined by the weak alignment of plagioclase phenocrysts (Fig. 3.4B) and alternating pink feldspar-quartz-rich bands and green feldspar-sericite ± chlorite-rich bands in the groundmass (Fig. 3.6C). The feldspar-quartz-rich bands typically contain recrystallised spherical and axiolitic spherulites. Large spherulites (0.5-2 cm) are elongated and aligned parallel to flow-banding. Some feldspar-sericite ± chlorite-rich bands contain relic banded perlite. Flow-bands vary from non-vesicular to highly vesicular or pumiceous. Pumiceous flow-bands typically occur at the margins of coherent rhyolite units and contain a chlorite-sericite-hematite stylolitic compaction foliation (Chapter 5).

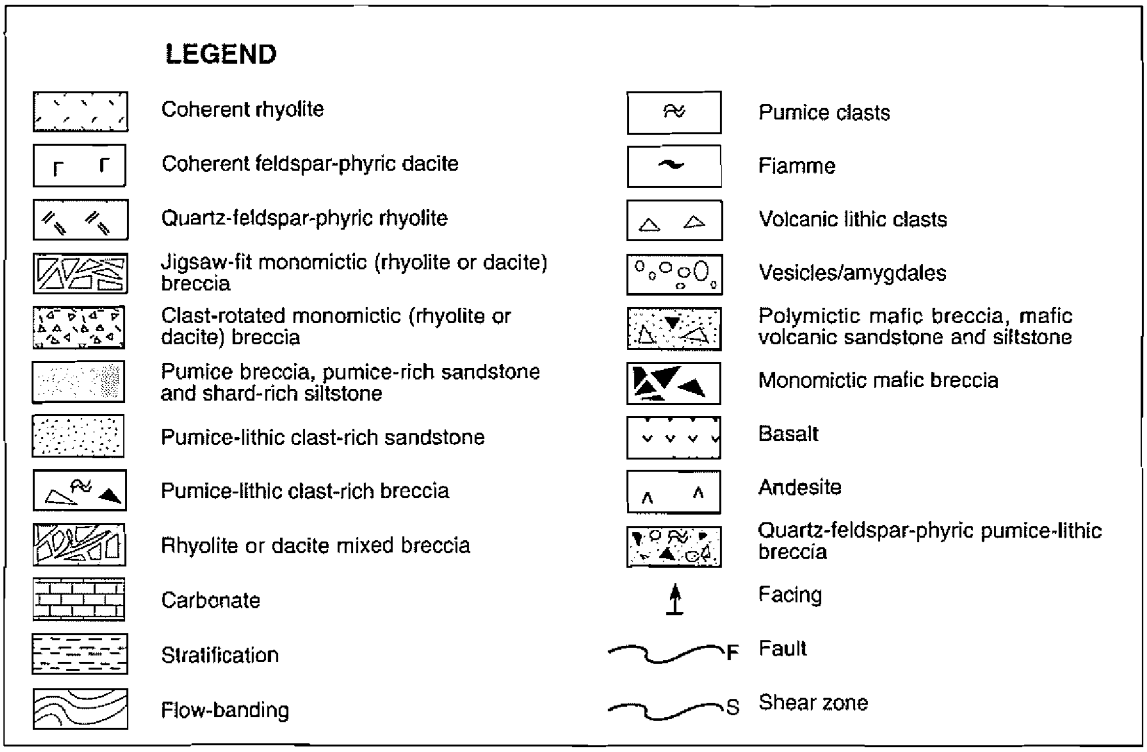
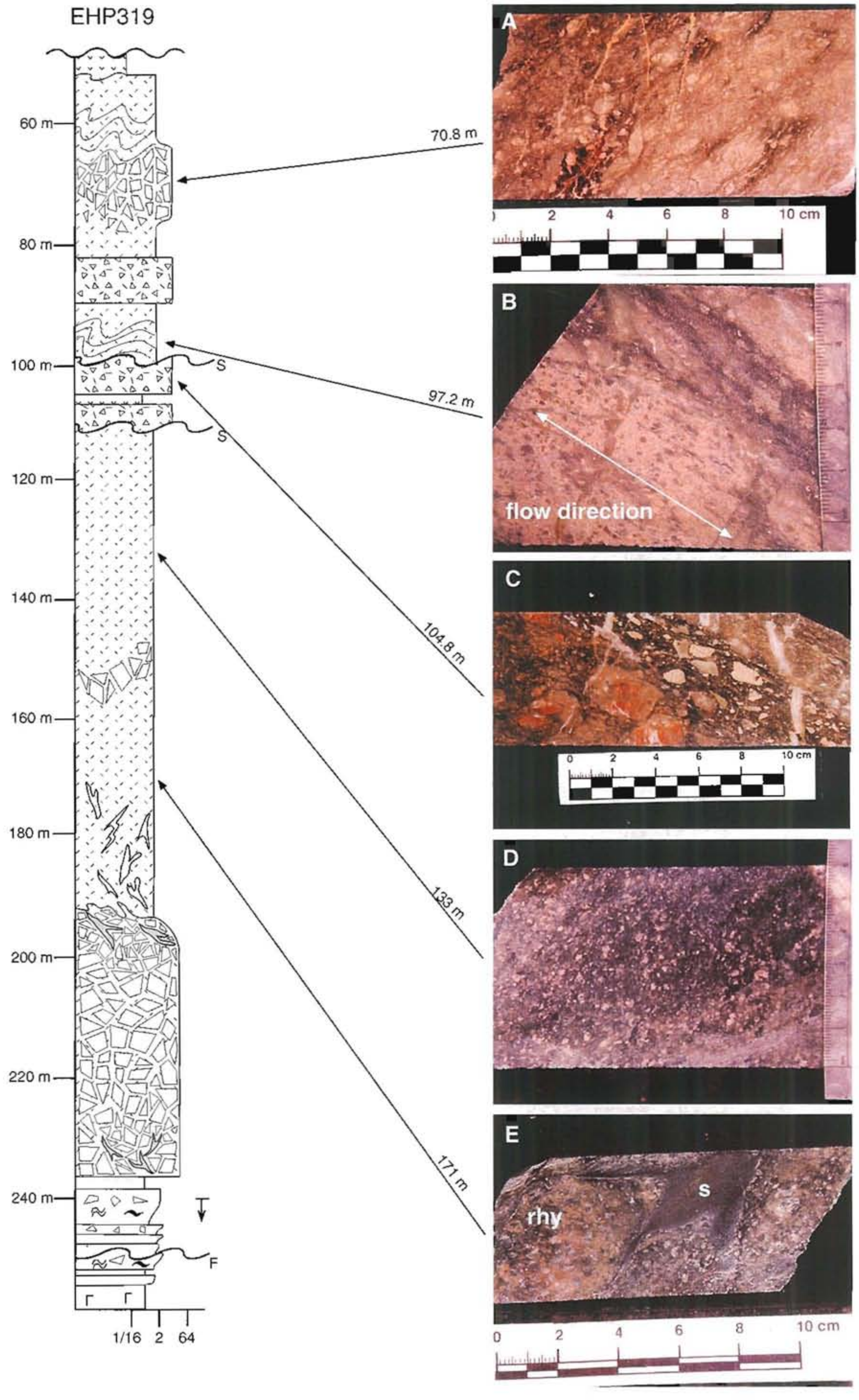


Figure 3.4: Symbols for graphic logs in Chapter 3.

Figure 3.4 continued: Graphic log for part of drill hole EHP319, through a feldspar-phyric rhyolitic lava. This section includes the lower contact marked by peperite (rhyolite mixed breccia) and in situ hyaloclastite (jigsaw-fit rhyolite breccia). The core facies is coherent rhyolite with sparse intervals of jigsaw-fit rhyolite breccia. The upper 40 m of the rhyolitic lava comprises intervals of massive and flow-banded coherent rhyolite, jigsaw-fit and clast-rotated rhyolite breccia. A. Jigsaw-fit rhyolite breccia (EHP319 70 m) composed of blocky, weakly flow-banded, feldspar-phyric rhyolite clasts. The breccia is strongly feldspar-quartz-sericite and chlorite-sericite altered. B. Flow-banded coherent rhyolite (EHP319 97 m). The flow-bands are defined by pink feldspar-quartz-sericite- and grey sericite-altered bands. Clear, 2 mm, plagioclase phenocrysts are aligned parallel with the flow-banding. C. Clast-rotated rhyolite breccia (EHP319 104 m) composed of blocky clast of feldspar-phyric rhyolite. The clasts commonly have planar margins and are locally jigsaw-fit. The red clasts are feldspar-quartz-sericite-altered, whereas the white clasts are feldspar-sericite-calcite-altered. The fine (<5 mm) clasts and matrix are replaced by dark green sericite. D. This coherent rhyolite (EHP319 133 m) is massive and strongly plagioclase-phyric (15%, 2 mm). The white, euhedral plagioclase phenocrysts are evenly distributed in the dark green sericite-chlorite-altered groundmass. E. This rhyolite mixed breccia (EHP319 171 m) is composed of grey siltstone clasts (s) surrounded by feldspar-phyric rhyolite (rhy). Siltstone clasts have very irregular shapes and are silicified at the margins. The rhyolite contains white plagioclase phenocrysts in a feldspar-quartz-sericite- and sericite-chlorite-altered groundmass.


EHP319
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120 m
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160 m
180 m
200 m
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240 m
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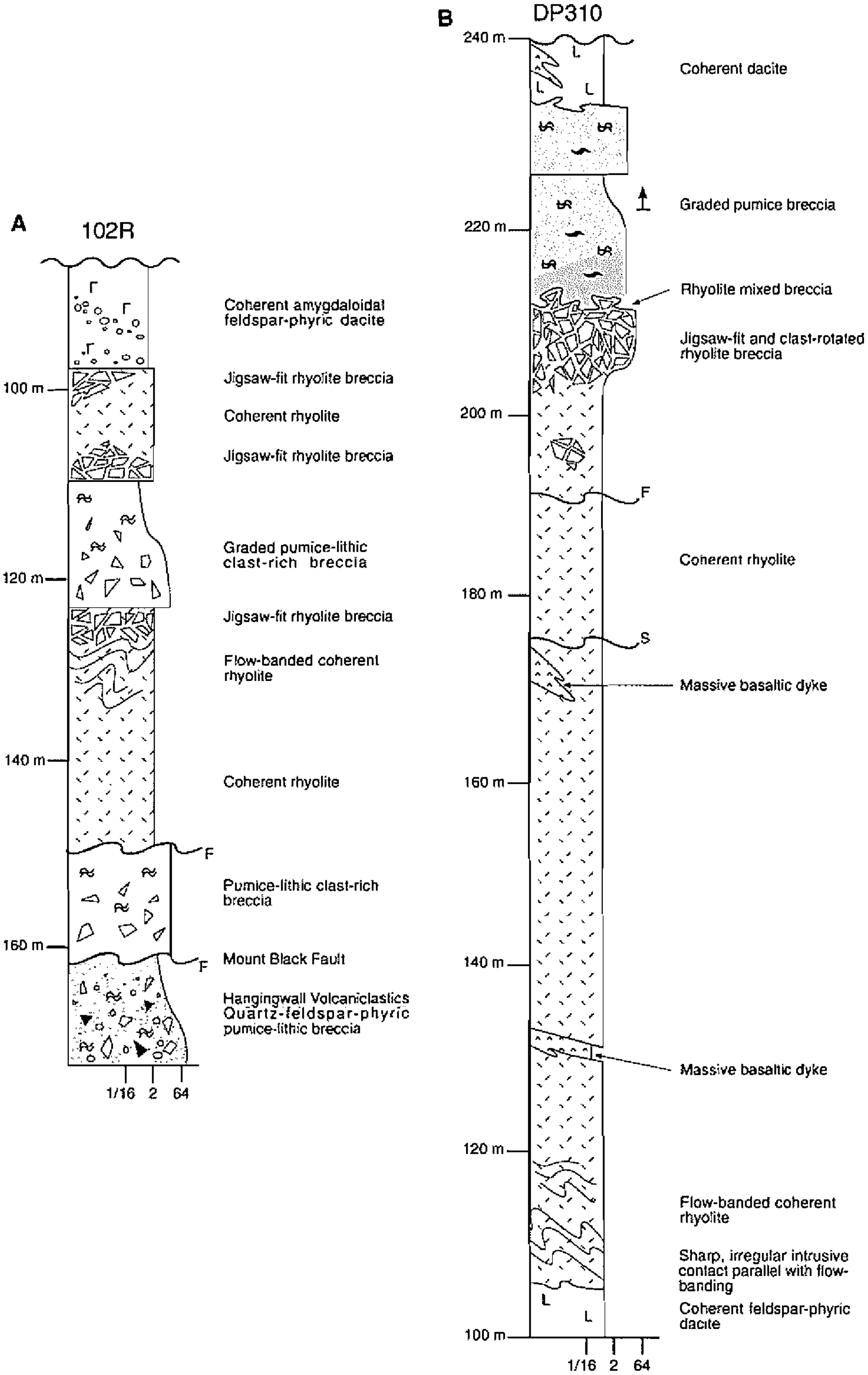
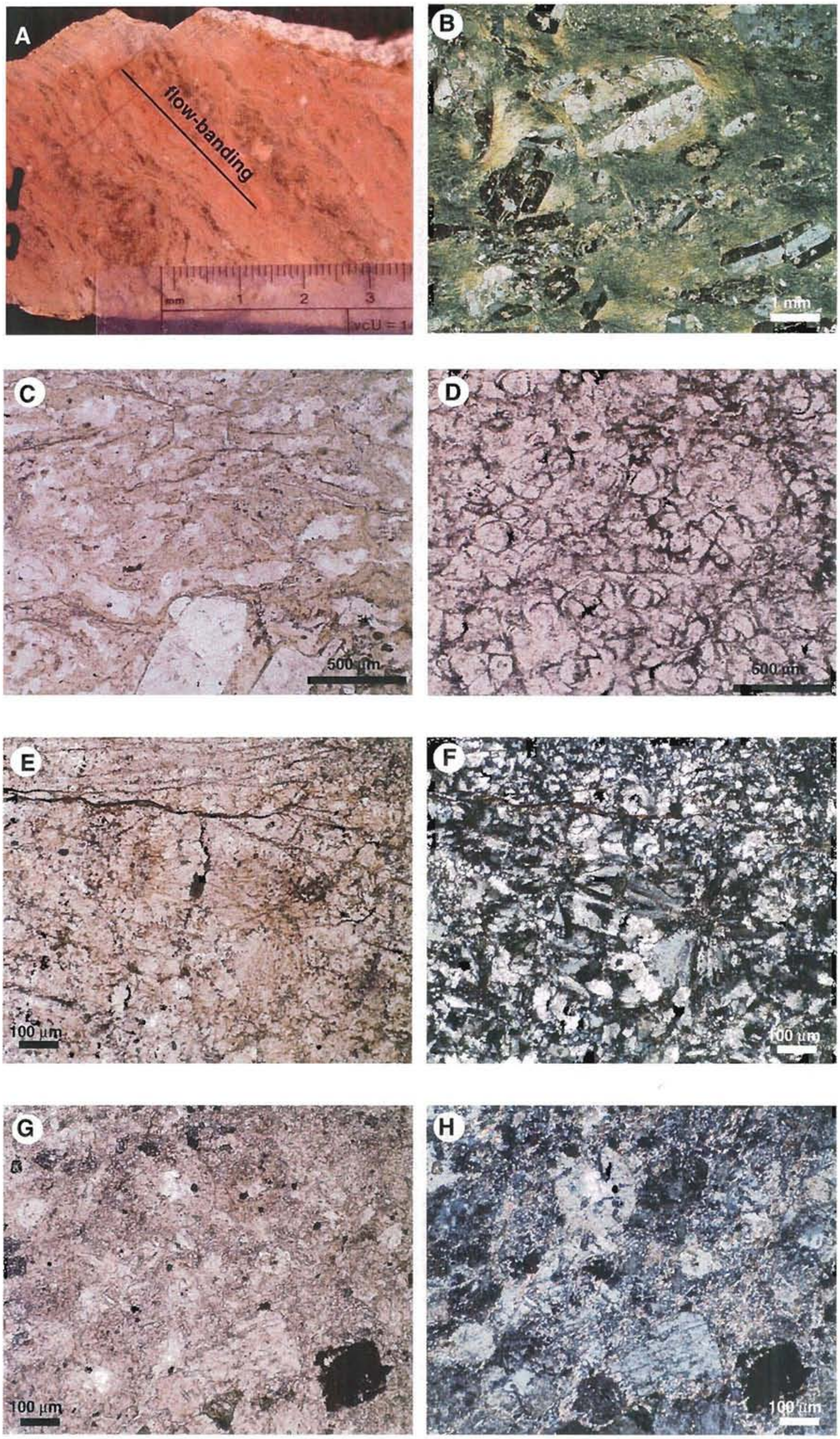


Figure 3.5: Two graphic logs through a feldspar-phyric rhyolite lava (A) and sill (B). See Figure 3.4 for legend to graphic log. A. A thin interval of coherent rhyolite grades up-hole into flow-banded coherent rhyolite and jigsaw-fit rhyolite breccia. Conformably overlying the jigsaw-fit rhyolite breccia is a 13 m-thick graded bed of pumice-lithic clast-rich breccia. Although the lower contact of the rhyolite has been removed by faulting, the conformable upper contact is consistent with a rhyolitic lava. B. A thick (110 m) interval of coherent rhyolite has an irregular intrusive lower contact (at 106 m) with coherent feldspar-phyric dacite. The upper contact (200-215 m) grades up-hole from coherent rhyolite to jigsaw-fit and clast-rotated rhyolite breccia (hyaloclastite) and then rhyolite mixed breccia (peperite). This interval of rhyolite mixed breccia contains blocky feldspar-phyric rhyolite and irregular pumice breccia clasts. The upper contact of the rhyolite mixed breccia grades into pumice breccia. The irregular intrusive lower contact and peperitic upper contact are consistent with the interpretation of this rhyolite facies association as a syn-volcanic sill.

Figure 3.6: Handspecimen and thinsection photographs of coherent rhyolite from the Mount Black Volcanics. A. Finely flow-banded, coherent rhyolite from the transmission line north of Mount Block (sample B2). It contains ~5% silicified plagioclase phenocrysts. The flow-banding is defined by alternating grey chlorite- and pink feldspar-quartz-sericite-altered bands. Convolute flow-bands wrap around domains of jigsaw-fit and clast-rotated, rhyolite breccia. B. Photomicrograph (xn) of coherent rhyolite (120R 591.6 m). This rhyolite contains 20%, euhedral, plagioclase phenocrysts and glomeroporphyritic clusters. Plagioclase phenocrysts are silicified and dusted with fine carbonate. The groundmass is intensely sericite-altered. C. Photomicrograph (ppl) of flow-banded, coherent rhyolite from the western side of Mount Black (sample R30). The groundmass is flow-banded, folded and brecciated. Flow-bands are defined by alternating pink sericite-feldspar- and white feldspar-quartz—altered bands. Albite-altered plagioclase phenocrysts are coated in thin films of sericite and have thin albite overgrowths. D. Photomicrograph (ppl) of perlitic, coherent rhyolite (120R 438 m). Fine arcuate, overlapping perlitic fractures are preserved by chlorite or sericite. The perlite kernels are feldspar-quartz-sericite-altered and overprinted by disseminated magnetite. Larger planar and curviplanar fractures define jigsaw-fit clasts. E. Photomicrograph (ppl) of densely microspherulitic, coherent rhyolite from the Murchison Highway, Rosebery (sample M105). Radiating trails of sericite in the groundmass highlight the originally fibrous texture of the spherulites. F. Photomicrograph (xn) of same view as E. The spherulites are partially recrystallised to feldspar and quartz crystals which are coated in thin films of sericite. G. Photomicrograph (ppl) of coherent rhyolite (BY2 53 m). The groundmass is densely micropoikolitic comprising patches of quartz and K-feldspar that enclose laths of albite. The groundmass is quartz-sericite-altered and overprinted by rhombs of calcite and chlorite-magnetite. H. Photomicrograph (xn) of same view as G.


A
flow-banding
mm
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2
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H
100 µm

Groundmass textures in coherent rhyolite may include: amygdales, quartzo-feldspathic mosaic, micropoikolitic quartz or K-feldspar (Fig. 3.6G), spherulites (Fig. 3.6E), microspherulites (<0.5 mm across), and classical and banded perlite (Fig. 3.6D). Amygdales are filled with a combination of quartz, chlorite, sericite and carbonate and are elongated parallel to flow-banding. The micropoikolitic texture comprises irregular quartz or feldspar crystals that enclose laths of albite (Figs. 3.6G and H). Spherulites consist of aggregates of fibrous feldspar and/or quartz crystals, which display radial extinction in thinsection (Figs. 3.6E and F). Some spherulites have been recrystallised to less fibrous feldspar and quartz crystals in which the originally fibrous texture is defined by thin trails of sericite. A fine-grained mosaic of quartz, feldspar, sericite, chlorite and carbonate commonly separates coalescing spherulites. Densely microspherulitic rhyolites have a fine sandy texture in handspecimen. Sericite or chlorite defines classical and banded perlitic fractures (Fig. 3.6D).

3.3.2 Monomictic rhyolite breccia facies

Monomictic rhyolite breccia typically occurs at the margins of and within coherent rhyolite (Figs. 3.4A, 3.4C). Contacts between monomictic rhyolite breccia facies and coherent rhyolite facies vary from sharp to gradational. Coherent rhyolite passes to fractured rhyolite, then into in situ and clast-rotated rhyolite breccia. In a few examples, this grades into graded and/or stratified rhyolite breccia (Fig. 3.7).

Monomictic rhyolite breccia units are limited in extent (typically less than 100 m, but up to 1 km) and thickness (2 to 60 m) (Figs. 3.2 and 3.3). This facies varies from clast-supported jigsaw-fit fabric to matrix-supported aggregates of rotated clasts (Fig. 3.8). It is generally massive, however sparse intervals of normally graded breccia to sandstone and intervals of diffusely stratified breccia also occur. The grainsize varies widely, with coarse (1-2 m) clasts occurring locally (Fig. 3.7).

Clasts are evenly plagioclase porphyritic and have blocky to splintery shapes bound by straight or planar to curviplanar edges (Figs. 3.8A and B). The dominant clasts are non-vesicular to weakly vesicular, massive to flow-banded clasts which contain perlitic or densely microspherulitic groundmasses. Sparse units comprising pumiceous or highly vesicular, feldspar-phyric rhyolite clasts also occur (Chapter 5) (Fig. 3.8C). The matrix (<2 mm) comprises feldspar crystals, crystal fragments and rhyolite clasts.

Alteration of this facies is typically complex with overprinting alteration facies resulting in false textures. These include: false matrix in jigsaw-fit rhyolite breccia (Fig. 3.8A), matrix-supported texture where alteration has obscured the margins of clasts, and apparent polymictic clast populations where originally identical clasts have been altered to different assemblages (Fig. 3.8D).

Four types of monomictic rhyolite breccia occur in the Mount Black Volcanics:

Jigsaw-fit rhyolite breccia facies: This facies is composed of jigsaw-fit, blocky and splintery clasts (Figs. 3.8A, B and C). Typically, clasts are perlitic and have planar and curviplanar margins. The average grainsize is less than 5 cm. Clasts are separated by small amounts of millimetre sized granular matrix. This facies can be both matrix- and clast-supported.

Clast-rotated rhyolite breccia facies: This breccia contains abundant blocky and splintery clasts, between

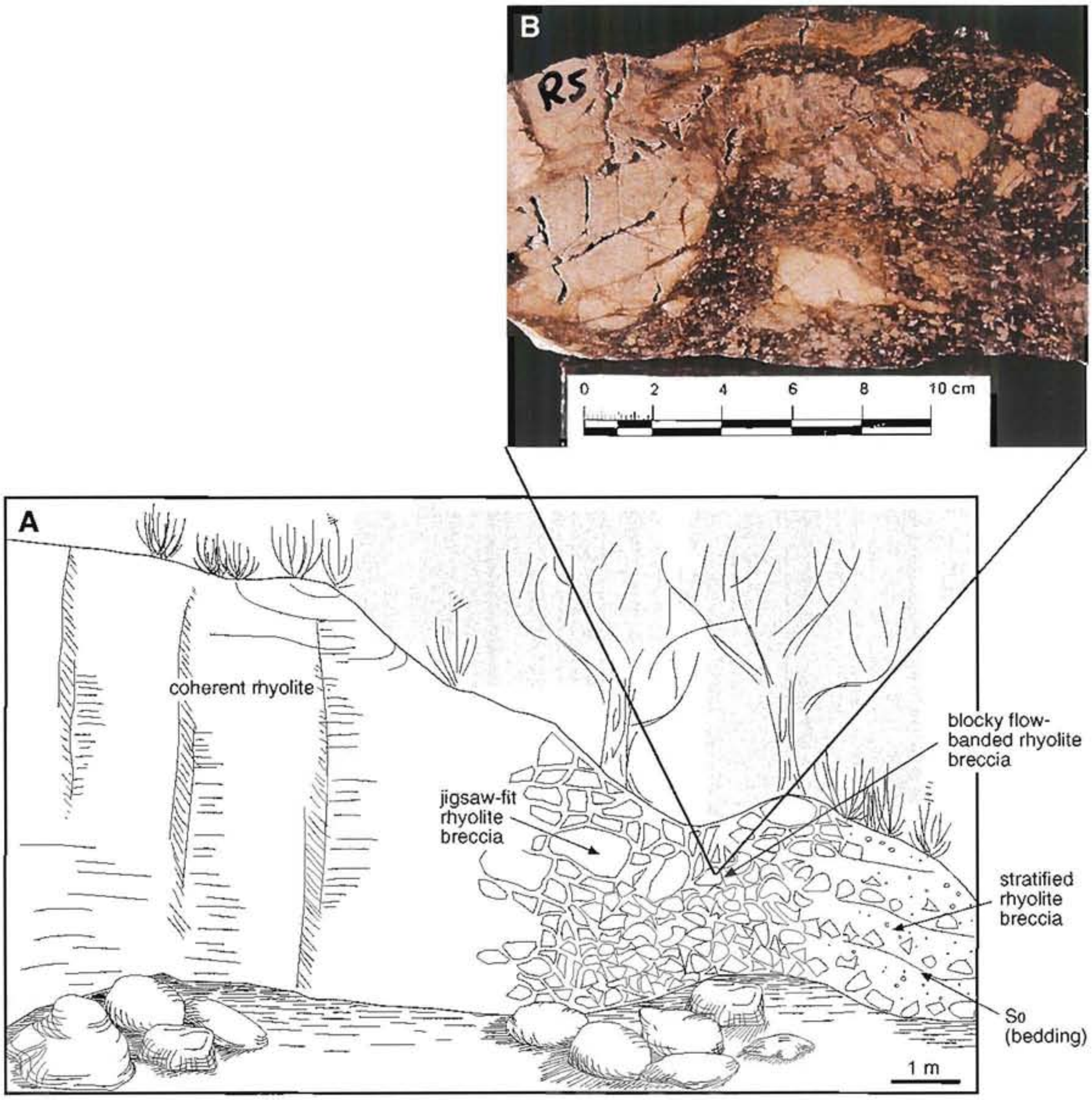


Figure 3.7: Monomictic rhyolite breccia in outcrop and handspecimen. A. This field sketch from the western side of Mount Black (drill pad 120R) shows gradational contacts from coherent rhyolite on the left, to jigsaw-fit, clast-rotated and blocky, flow-banded rhyolite breccia. Blocky, flow-banded rhyolite breccia grades into graded and stratified rhyolite breccia (far right). The monomictic rhyolite breccia facies are poorly sorted and vary from clast- to matrix-supported textures. B. Blocky, flow-banded rhyolite breccia (sample R50) is composed of blocky and splintery, massive and flow-banded, feldspar-phyric rhyolite clasts and plagioclase crystals. Flow-bands in the clasts are commonly perlitic or spherulitic. The clasts are feldspar-quartz-sericite- and sericite-chlorite-altered. The groundmass is intensely sericite-altered.

1 mm to 10 cm in diameter. Clast margins are fine grained (<100 mm) with planar to curviplanar surfaces. Clast rotation is implied where flow-banding, banded perlite or tube vesicles within adjacent clasts occurs at very different angles.

Blocky, flow-banded rhyolite breccia facies: Blocky, flow-banded rhyolite breccia is composed of a mixture of clasts with different groundmass textures but is dominated by flow-banded clasts (Fig. 3.8D). Blocky and tabular clasts range in grainsize from 1 cm to 2 m. Clasts are close-packed and there is a paucity of matrix. Clasts typically have straight or ragged edges. Adjacent clasts contain flow-banding at different orientations. Locally clasts show jigsaw-fit texture (Fig. 3.7A). In a few examples, the blocky clasts are pumice (Chapter 5).

Graded and/or stratified rhyolite breccia facies: This facies is commonly spatially associated with coherent rhyolite, clast-rotated rhyolite breccia or blocky, flow-banded rhyolite breccia (Fig. 3.7A). Beds of graded and/or stratified rhyolite breccia have sharp basal contacts, massive bodies and normally graded sandstone tops or they are diffusely stratified. Beds are typically up to 20 m thick. This moderately poorly sorted facies comprises blocky, massive or flow-banded rhyolite clasts. Clasts range in grainsize from 1 mm to 20 cm and have planar or curviplanar margins.

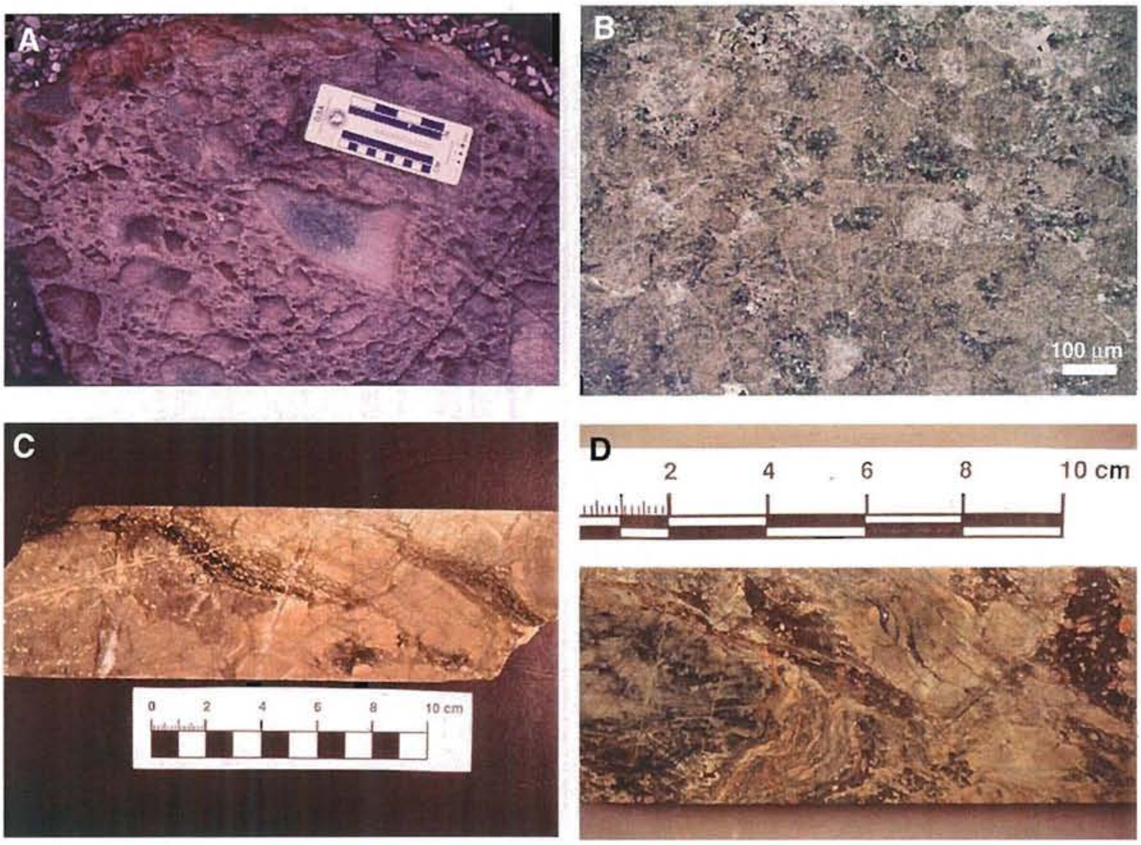


Figure 3.8: Handspecimen and thinsection photographs of monomictic rhyolite breccia in the Mount Black Volcanics. A. Jigsaw-fit feldspar-phyric rhyolite breccia from the shore of Lake Rosebery at Tullah (sample T1). This breccia is composed of blocky, perlitic clasts with planar and curviplanar edges typical of clasts produced by quench fragmentation. The groundmass in the clasts is sericite-chlorite-altered and fine clasts in the matrix and fractures between clasts are feldspar-quartz-sericite-altered. The feldspar-quartz-sericite alteration has been more resistant to weathering and forms ridges on the outcrop. B. Photomicrograph (ppl) of jigsaw-fit rhyolite breccia on the Pieman Road (sample PR18). Blocky clast margins are defined by feldspar-quartz-filled or -altered fractures. The clasts are strongly recrystallised to a mosaic of feldspar-quartz-sericite and relic feldspar-filled perlitic factures are preserved. C. Jigsaw-fit and clast-rotated rhyolite breccia (120R 102.6 m). This breccia is dominated by jigsaw-fit, finely flow-banded and pumiceous feldspar-phyric rhyolite clasts. This breccia is clast-supported, with small volumes of fine-grained matrix separating clasts. The clasts are tabular in shape and typically have straight edges. Flow-bands are defined by sericite-chlorite- and feldspar-quartz-sericite-altered bands. Plagioclase phenocrysts and crystals are strongly calcite-altered. D. Blocky, flow-banded rhyolite breccia (128R 157.5 m). This interval of monomictic rhyolite breccia is massive, poorly sorted, clast- and matrix-supported, and contains randomly oriented plagioclase-phyric rhyolite clasts. The rhyolite clasts contain a variety of groundmass textures including: massive, perlitic, spherulitic, pumiceous and flow-banded. Clasts commonly contain chlorite-filled fractures perpendicular to their long axis. These are interpreted to have formed during the deformation and fragmentation of viscous rhyolite during autobrecciation. The alteration is complex with domains of orange and cream feldspar-quartz-sericite, cream carbonate, pale green sericite and feldspar and dark green sericite-chlorite-altered rhyolite.

3.3.3 Rhyolite mixed breccia facies

This facies is composed of rhyolite clasts (2 mm to 6 cm in diameter) in a matrix of pumice breccia, pumice-lithic clast-rich breccia, sandstone or siltstone. In sparse examples of this facies, the rhyolite clasts are pumiceous (Chapter 5). Intervals of rhyolite mixed breccia facies range in thickness from a few ten's of centimetres to 20 m. They occur in small lenses (<50 m in length) associated with the margins of coherent rhyolites in the Mount Black Volcanics (Fig 3.4, 170-200 m, Fig 3.5B, 212-215 m and Fig. 3.9, 365-400 m).

Intervals of rhyolite mixed breccia are massive, poorly sorted and vary from clast- to matrix-supported. In intervals of clast-supported rhyolite mixed breccia, the matrix occurs as irregular, silicified wisps or lenses between rhyolite clasts (Figs. 3.4E and 3.9E). In matrix-supported facies, isolated or jigsaw-fit clusters of rhyolite clasts are dispersed in the matrix. The rhyolite clasts are blocky to ragged and angular with planar and curviplanar margins (Fig. 3.9E). They are mineralogically identical to the coherent rhyolite facies and are typically massive perlite.

Gradations between coherent rhyolite, jigsaw-fit rhyolite breccia and rhyolite mixed breccia are common at the margins of coherent rhyolite units. Rhyolite mixed breccia facies also commonly grades into pumice breccia or pumice-lithic clast-rich breccia, sandstone or siltstone. Typically coherent rhyolite grades into clast-supported rhyolite mixed breccia facies with stringers and wispy clasts of silicified siltstone (Figs. 3.4 and 3.5B). The abundance of siltstone lenses increases towards the contact. This grades into massive or diffusely laminated siltstone that contains rhyolite clasts with curviplanar margins (matrix-supported rhyolite mixed breccia facies). The laminations in the siltstone are disrupted and contorted. Siltstone at the contact with rhyolite mixed breccia facies is pale grey, massive and silicified.

3.3.4 Interpretation

The coherent rhyolite, monomictic rhyolite breccia and rhyolite mixed breccia facies are closely spatially associated. Locally intervals of coherent rhyolite, monomictic rhyolite breccia and rhyolite clasts within the rhyolite mixed breccia are both mineralogically and texturally similar and many have gradational contacts. This suggests that these three facies are genetically related and may be part of the same eruptive or depositional event.

The spatial, textural and mineralogical relationship, and gradational contacts between intervals of monomictic rhyolite breccia and coherent rhyolite are consistent with clasts in the monomictic rhyolite breccia being derived from disintegration of coherent rhyolite. The abundance of jigsaw-fit pattern in the jigsaw-fit and clast-rotated rhyolite breccia facies indicates that fragmentation was in situ. Perlitic fractures in rhyolite clasts in the jigsaw-fit and clast-rotated rhyolite breccia facies reflect the originally glassy nature of these facies (Ross and Smith, 1955). These facies comprise originally glassy, blocky and splintery clasts with planar and curviplanar surfaces identical to clasts produced by quench fragmentation (cf. Pichler, 1965; Yamagishi, 1987). This is consistent with the interpretation of the jigsaw-fit and clast-rotated rhyolite facies as hyaloclastite (cf. Pichler, 1965). Jigsaw-fit rhyolite breccia facies is interpreted as in situ hyaloclastite, whereas clasts in the clast-rotated rhyolite breccia facies have been rotated after quench fragmentation. A gradation from jigsaw-fit to clast-rotated rhyolite breccia adjacent to intervals of coherent rhyolite suggests that rotation may have been the result of

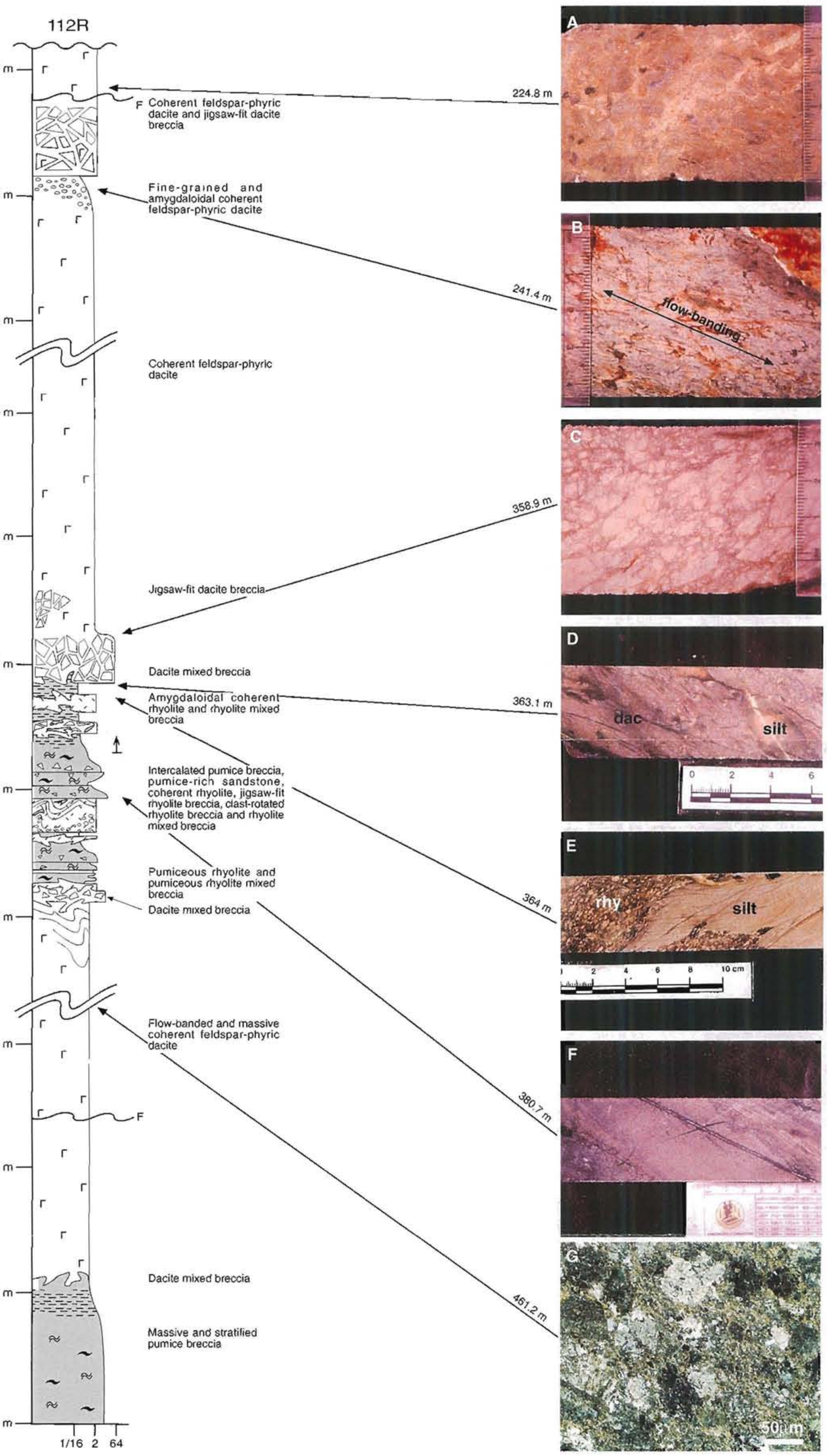


Figure 3.9: Graphic log through two thick, feldspar-phyric dacite facies associations and a thin rhyolite facies association in drill hole 112R. The upper dacite (236-364 m) has a planar upper contact and gradational lower contact with jigsaw-fit dacite breccia and dacite mixed breccia. It is interpreted as a lava or dome. The lower dacite (393-518 m) has peperitic (dacite mixed breccia) upper and lower contacts and is interpreted to be at least partially intrusive. Both dacite facies association include cores of coherent feldspar-phyric dacite. See Figure 3.4 for legend to graphic log. A. Jigsaw-fit dacite breccia (112R 224.8 m). The blocky feldspar-phyric dacite clasts are finely flow-banded and feldspar-quartz-sericite-altered. Fractures which defined the edges of the jigsaw-fit clasts are carbonate altered and weathered. B. Weakly flow-banded, coherent feldspar-phyric dacite (112R 241.4 m). The flow-banding is defined by elongated and aligned amygdales. C. Jigsaw-fit dacite breccia (112R 358.9 m). Blocky feldspar-phyric dacite clasts have planar and curviplanar margins and a jigsaw-fit texture consistent with in situ hyaloclastite. D. Dacite mixed breccia (112R 363.1 m) comprises ragged irregular clasts of silicified siltstone (silt) in feldspar-phyric dacite. E. Rhyolite mixed breccia (112R 364 m) composed of irregular lens of siltstone (silt) in feldspar-phyric rhyolite (rhy). F. Interbedded pumice-rich sandstone and shard-rich siltstone (112R 380.7 m). The pumice-rich sandstone comprises pumice, plagioclase crystal fragments and fiamme. G. Photomicrograph (xn) of the micropoikolitic groundmass in the coherent feldspar-phyric dacite (112R 461.2 m). Laths of albite are enclosed in K-feldspar which is partly replaced by quartz and disseminated sericite.

endogenous growth of the associated rhyolite, or due to clasts rolling down slope. Clasts have not undergone significant transport as they still have planar and curviplanar surfaces.

Blocky, flow-banded rhyolite breccia facies is clast-supported and dominated by flow-banded, tabular and blocky clasts. This is texturally identical to autobreccia which results from non-explosive flow fragmentation. Autobrecciation occurs when the more viscous parts of a moving magma body respond to locally higher strain rates by deforming plastically and fragmenting into blocky slabs (Fisher, 1960). The close spatial association and gradational contacts between intervals of blocky, flow-banded rhyolite breccia and coherent rhyolite with similar phenocryst populations are consistent with clasts derived from fragmentation of the coherent rhyolite becoming progressively rotated and separated away from the rhyolite. Local jigsaw-fit textures within the blocky, flow-banded rhyolite breccia facies record the progressive disintegration of larger clasts.

Clast shapes and arrangements in the monomictic rhyolite breccia facies are typical of in situ, and clast-rotated autobreccia and hyaloclastite (cf. Pichler, 1965). However, a few intervals of graded and/or stratified rhyolite breccia suggest local resedimentation occurred. The graded and/or stratified rhyolite breccia facies contains angular blocky clasts that are inconsistent with significant reworking. The poorly-sorted, normally graded and diffusely stratified nature, sharp basal contacts and lateral extents (up to 1 km) suggest that deposition was from subaqueous mass flows. Bedforms are consistent with density sorting or tractional transport and may reflect deposition from debris flows or density-modified grain-flows, respectively (cf. Lowe, 1976, 1982).

Rhyolite mixed breccia facies occurs at the gradational contact between coherent rhyolite and pumice breccia or pumice-lithic clast-rich breccia, sandstone or siltstone. Clasts in the rhyolite mixed breccia are mineralogically and texturally identical to the adjacent coherent rhyolite, which suggests that they are genetically related. The occurrence of local jigsaw-fit textures indicates that fragmentation was in situ (cf. Pichler, 1965). The blocky and splintery shapes and curviplanar surfaces on some of the rhyolite clasts in the rhyolite mixed breccia are consistent with brittle fragmentation, most likely quench fragmentation (cf. Pichler, 1965; Yamagishi, 1987).

The matrix in the rhyolite mixed breccia (pumice breccia or pumice-lithic clast-rich breccia, sandstone or siltstone) is typically homogenous in character or contains deformed laminations, whereas away from the contact with the coherent rhyolite and rhyolite mixed breccia, pumice breccia or pumice-lithic clast-rich breccia, sandstone or siltstone are graded, diffusely stratified or laminated. This indicates that the matrix was unconsolidated and probably wet at the time of mixing. Local homogenisation may be the result of fluidisation of unconsolidated sediment by heated pore fluid (Kokelaar, 1982). Silicification of the matrix immediately adjacent to the coherent rhyolite and rhyolite clasts is consistent with induration.

The presence of rhyolite mixed breccia at the bases and tops of coherent rhyolite, in situ quench fragmentation of clasts in the rhyolite mixed breccia facies, interfingering of pumice breccia or pumice-lithic clast-rich breccia, sandstone or siltstone with the coherent rhyolite, and homogenisation and local induration of the matrix are all consistent with the interpretation of the rhyolite mixed breccia facies as peperite (cf. Kokelaar, 1982).

Peperite is rock type which forms in situ by the disintegration of magma intruding and mingling with unconsolidated, typically wet sediments (Fisher, 1960, Williams and McBirney, 1979; Busby-Spera and White, 1987; White et al., 2000). It commonly occurs at the contacts of shallow intrusions that have been injected into wet unconsolidated sediment and along the basal contacts of lavas with underlying sediment (Fisher, 1960; Williams and McBirney, 1979; Busby-Spera and White, 1987; McPhie et al., 1993).

Textures and contact relationships of the rhyolites facies associations in the Mount Black Volcanics are consistent with rhyolitic lavas, domes, cryptodomes and syn-volcanic sills (cf. De Rosen-Spence et al., 1980; Kokelaar, 1982; Branney and Suthren, 1988; Cas et al., 1990; Kano et al., 1991). The association of resedimented autobreccia and hyaloclastite (graded and/or stratified rhyolite breccia) with some intervals of coherent rhyolite in the Mount Black Volcanics indicates at least partial extrusion of the rhyolites. In contrast, the presence of peperite (rhyolite mixed breccia facies) along top contacts, irregular upper contacts and the conformable geometry of some rhyolites are consistent with the interpretation that they are shallow syn-volcanic sills.

3.4 Quartz-feldspar-phyric rhyolite facies association

The quartz-feldspar-phyric rhyolite facies association includes two lithofacies: quartz-feldspar-phyric rhyolite and quartz-feldspar-phyric rhyolite-siltstone breccia facies.

3.4.1 Quartz-feldspar-phyric rhyolite

Massive quartz-feldspar-phyric rhyolite units are exposed on Mount Read, along the Murchison Highway and the Pieman Road (Fig. 3.1). They have irregular tabular geometries that locally cross cut stratigraphy. Quartz-feldspar-phyric rhyolite units are up to 200 m thick and extend laterally for up to 1500 m. Sparse flow-banding occurs at the margins of massive quartz-feldspar-phyric rhyolite units. The only observed contacts occur on the Murchison Highway and on the summit of Mount Read, where quartz-feldspar-phyric rhyolite facies grades into quartz-feldspar-phyric rhyolite-siltstone breccia facies.

Quartz-feldspar-phyric rhyolite facies is characterised by 5-15%, 1-2 mm plagioclase and quartz phenocrysts. The proportion of plagioclase to quartz varies among units. Plagioclase phenocrysts are partially altered to albite or microcrystalline quartz and dusted with sericite. Quartz phenocrysts are large (2 mm), clear, embayed crystals that are fractured and are typically enclosed in a spherulitic crust. The densely microspherulitic or micropoikolitic groundmasses are quartz-sericite-altered and contain disseminated chlorite-magnetite. Interstitial sericite and chlorite occurs between the spherulites and micropoikolitic quartz.

3.4.2 Quartz-feldspar-phyric rhyolite-siltstone breccia

Quartz-feldspar-phyric rhyolite-siltstone breccia is massive, thin (~2 m) and occurs at the contact between quartz-feldspar-phyric rhyolite and siltstone. This facies consists of irregular lenses and wispy clasts of silicified siltstone within massive quartz-feldspar-phyric rhyolite. The siltstone clasts (1 to 15 cm) are pale grey and massive.

3.4.3 Interpretation

The geometry and oblique nature of the quartz-feldspar-phyric rhyolite units suggests they are dykes. The quartz-feldspar-phyric rhyolite-siltstone breccia facies is texturally similar to peperite. Peperitic contacts suggest that intrusion of the quartz-feldspar-phyric rhyolite dykes occurred prior to lithification, when the silt was unconsolidated and probably wet (cf. Kokelaar, 1982).

3.5 Dacite facies association

The dacite facies association comprises three facies: coherent feldspar-phyric dacite, monomictic dacite breccia and dacite mixed breccia.

3.5.1 Coherent feldspar-phyric dacite

Coherent feldspar-phyric dacites are the most abundant facies in the Mount Black and Sterling Valley Volcanics. Thick intervals of dacite occur on the eastern flank of Mount Black and are exposed along the Murchison Highway and in drill holes MBD1 to MBD4 (Fig. 3.1). They also occur sporadically through the northern Central Volcanic Complex with good examples exposed on the summit of Mount Read and Pieman Road (Fig. 3.1). Coherent feldspar-phyric dacites are typically thick (10 to 300 m), massive, weakly vesicular and red-brown to grey-green in colour. They have lateral extents of up to 2 km. Margins are locally flow-banded parallel to the contacts or associated with monomictic dacite breccia (Fig. 3.9). Upper contacts include: faults, shear zones, irregular chilled margins, gradations with monomictic dacite breccia and dacite mixed breccia. The lower contacts are sharp and planar or irregular, incorporating clasts of the underlying unit (Fig. 3.9).

The coherent feldspar-phyric dacite facies is characterised by 5-20%, 1-3 mm, zoned, euhedral plagioclase phenocrysts (Fig. 3.10B). Sparse examples have greater than 20% plagioclase. The plagioclase phenocrysts commonly occur in glomeroporphyritic aggregates up to 1 cm in diameter with interstitial chlorite and magnetite (Fig. 3.10C). Plagioclase phenocrysts are variably altered to albite, sericite, carbonate, chlorite, epidote and hematite (Fig. 3.10D).

Groundmass textures include: quartzo-feldspathic mosaic, micropoikolitic quartz and K-feldspar (Fig. 3.9G), microspherulites, coalescing spherulites (Fig. 3.10E), lithophysae (Fig. 3.10F) and classical perlite (Figs. 3.10A and C). The cores of the recrystallised microspherulites contain blebs of clear quartz about 100 μm in diameter (Fig. 3.10F). The quartz-filled vughs in the lithophysae are elongate with cuspate margins.

3.5.2 Monomictic dacite breccia facies

The monomictic dacite breccia facies is texturally similar to the monomictic rhyolite breccia facies (section 3.3.2) and is spatially associated with coherent feldspar-phyric dacite and dacite mixed breccia (Fig. 3.9).

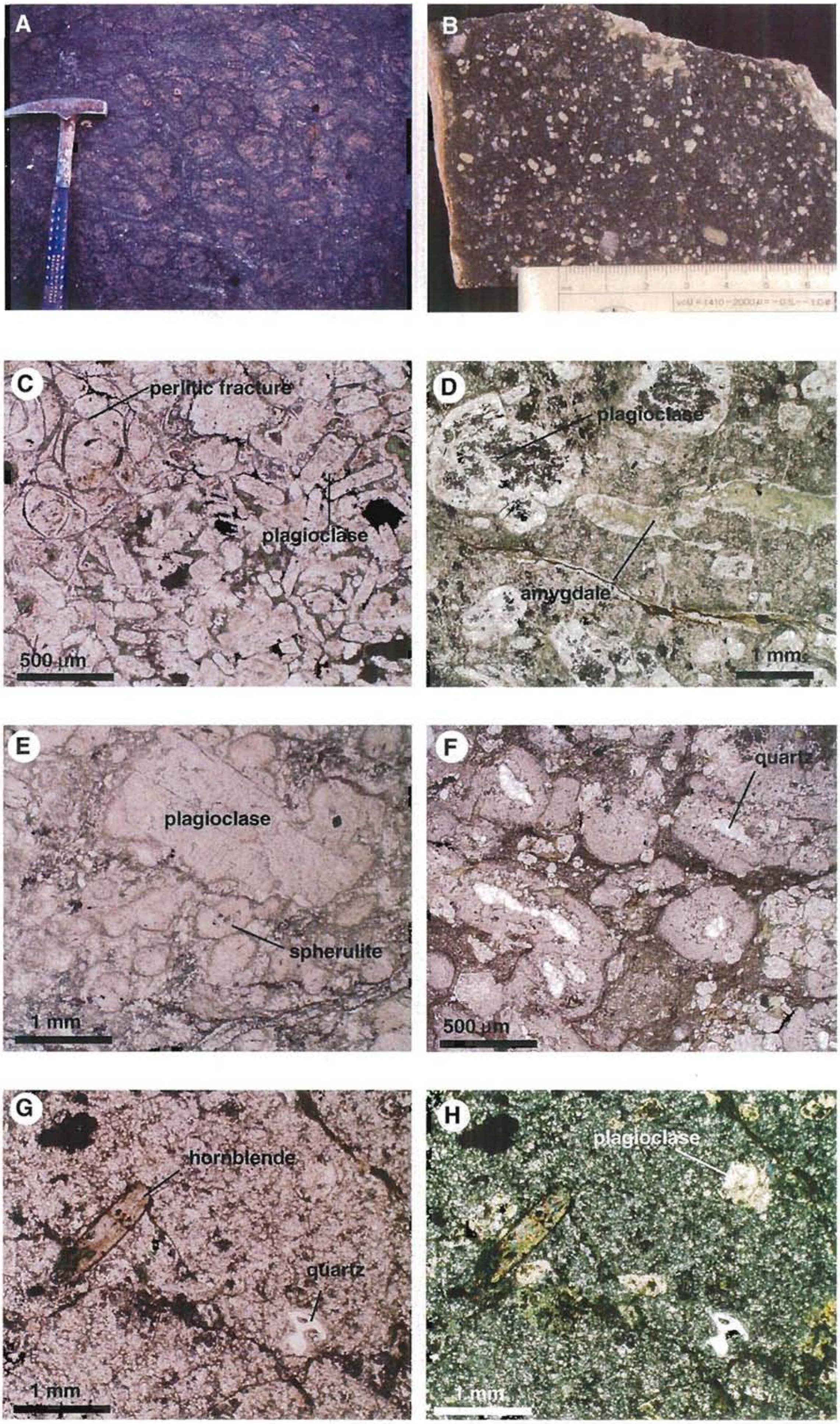
3.5.3 Dacite mixed breccia facies

Dacite mixed breccia facies is similar to rhyolite mixed breccia facies (section 3.3.3).

3.5.4 Interpretation

The dacite facies association is similar to the rhyolite facies association and is interpreted in the same way. The monomictic dacite breccia facies is interpreted as hyaloclastite and the dacite mixed breccia facies is interpreted as dacitic peperite.

Figure 3.10: Handspecimen and thinsection photographs of coherent feldspar-phyric and feldspar-hornblende-phyric dacite in the Mount Black and Sterling Valley Volcanics. A. Megaperlite in coherent feldspar-phyric dacite on the Pieman Road (sample PR1). Arcuate perlitic fractures are highlighted by dark grey, sericite-chlorite alteration, whereas the perlite kernels are pink feldspar-quartz-sericite-altered. B. Coherent feldspar-hornblende-phyric dacite on the Pieman Road (sample PR58) is massive and evenly porphyritic. The hornblende phenocrysts are replaced by epidote. The groundmass is weakly chlorite-epidote altered. C. Photomicrograph (ppl) of arcuate perlitic fractures in coherent feldspar-phyric dacite (sample PR1). The euhedral plagioclase phenocrysts occur in a glomeroporphyritic cluster with interstitial chlorite and magnetite. The perlitic fractures are filled with sericite, which is partially replaced by chlorite. The perlitic kernels are feldspar-quartz-sericite-altered. D. Photomicrograph (ppl) of crystal-rich, coherent feldspar-phyric dacite from the eastern flank of Mount Black (sample MBE4). Plagioclase phenocrysts are extensively replaced by calcite and epidote. The groundmass is a fine feldspar-quartz-sericite mosaic and contains elongate quartz-chlorite filled amygdales. E. Photomicrograph (ppl) of densely microspherulitic, coherent feldspar-phyric dacite, western side of Mount Read (EHP319 296.6). The albite-altered plagioclase phenocrysts have spherulitic albite-quartz overgrowths. The groundmass contains abundant spherical, feldspar-quartz-sericite-altered spherulites that are coated in a thin films of sericite. Interstitial to the spherulites is a mosaic of feldspar-quartz-sericite which is partly replaced by chlorite. F. Photomicrograph (ppl) of quartz-filled lithophysae in a coherent feldspar-phyric dacite (sample M89). The lithophysae are in a chlorite-rich groundmass. G. Photomicrograph (ppl) of coherent feldspar-hornblende-phyric dacite (sample M25). Phenocrysts include euhedral plagioclase, prismatic hornblende and embayed quartz. The hornblende is partially replaced by chlorite. The groundmass is a fine quartzo-feldspathic mosaic. H. Photomicrograph (xn) of view G.


A
B
C
perlitic fracture
plagioclase
500 μm
D
plagioclase
amygdale
1 mm
E
plagioclase
spherulite
1 mm
F
quartz
500 μm
G
hornblende
quartz
1 mm
H
plagioclase
1 mm

Hydration and low-temperature devitrification textures (perlite, quartzo-feldspathic mosaic) and high temperature crystallisation textures (spherulites, lithophysae, micropoikolitic texture) in the coherent feldspar-phyric dacite facies indicate that they were originally partly glassy and partly crystalline (cf. Ross and Smith, 1955; Lofgren, 1971; Bigger and Hanson, 1992; McArthur et al., 1998).

Facies characteristics and contact relationships in the dacite facies association are consistent with the interpretation lavas and sills. Dacite lavas, domes and sills in the Mount Black and Sterling Valley Volcanics are dominated by coherent feldspar-phyric dacite with variable amounts of in situ and clast-rotated hyaloclastite, autobreccia, and peperite. The dacite lavas and sills are best distinguished based on their contact relationships as they have identical primary volcanic textures and compositions (Chapter 4).

Dacite facies associations that include thick intervals of hyaloclastite (monomictic dacite breccia) and have planar conformable upper contacts with the overlying rocks are interpreted to be lavas or domes. They are typically 100 to 200 m thick and have lateral extents of 100 m to 2 km.

Dacite facies associations which contain peperite (dacite mixed breccia facies) at the upper contact or have irregular upper contacts are interpreted to be intrusions. These dacite sills are typically tabular, thick (100 m), laterally extensive (2 km) and internally massive with flow-banded margins. The abundance of peperite associated with the dacite sills suggests that they were emplaced into unconsolidated, probably wet, sediment below the seafloor (cf. Hanson and Wilson, 1993).

3.6 Feldspar-hornblende-phyric dacite facies association

Feldspar-hornblende-phyric dacite facies association includes two facies: coherent feldspar-hornblende-phyric dacite and monomictic feldspar-hornblende dacite breccia.

3.6.1 Coherent feldspar-hornblende-phyric dacite

Coherent feldspar-hornblende-phyric dacite is exposed along the Murchison Highway, the Pieman Road in the Mackintosh Bridge area, in the Sterling Saddle and on the western flank of Mount Black (Fig. 3.1). Coherent feldspar-hornblende-phyric dacite units are massive and brown in colour. They are 100 to 800 m thick and extend up to several kilometres laterally. The coherent feldspar-hornblende-phyric dacite near Mackintosh Bridge has gradational contacts with thick (200 m), jigsaw-fit and clast-rotated feldspar-hornblende-phyric breccia. No contacts of the feldspar-hornblende-phyric dacites along the Murchison Highway were observed.

This facies is massive and locally flow-banded or contains flow-aligned phenocrysts. Coherent feldspar-hornblende-phyric dacites comprise 10-20% total crystals including: 1-2 mm euhedral plagioclase (7-15%), 1 mm prismatic hornblende (3-5%) and 1 mm quartz (1%) phenocrysts in a fine-grained groundmass of feldspar, quartz, sericite, magnetite and chlorite (Fig. 3.10G and H). Hornblende and plagioclase are also present in 2-6 mm aggregates (glomeroporphyritic clusters) with interstitial chlorite ± magnetite. Epidote, magnetite or chlorite commonly replace hornblende phenocrysts. The plagioclase crystals are dusted with sericite and epidote.

Groundmass textures are dominated by perlite but also include microspherulites (Fig. 3.10G) and micropoikolitic quartz.

3.6.2 Monomictic feldspar-hornblende-phyric dacite breccia facies

Monomictic feldspar-hornblende-phyric dacite breccia facies is texturally similar to monomictic rhyolite breccia facies (section 3.3.2), particularly jigsaw-fit rhyolite breccia and clast-rotated rhyolite breccia. This facies is spatially associated with coherent feldspar-hornblende-phyric dacite facies.

3.6.3 Interpretation

In the feldspar-hornblende-phyric dacite facies association near the Mackintosh Bridge, identical mineralogies, the spatial association and gradational contact between coherent feldspar-hornblende-phyric dacite and hyaloclastite (monomictic feldspar-hornblende-phyric dacite breccia) are consistent with the interpretation of a thick (1 km) feldspar-hornblende-phyric dacitic lava or dome. The margins of the lava were quench fragmented resulting in a thick (>100 m) carapace of in situ and clast-rotated hyaloclastite. The abundance of perlite in the coherent feldspar-hornblende-phyric dacite and in clasts in the monomictic feldspar-hornblende-phyric dacite breccia indicate that much of the feldspar-hornblende-phyric dacite lava was initially glassy.

Other exposures of feldspar-hornblende-phyric dacite facies association in the Mount Black Volcanics lack contacts making interpretation difficult.

3.7 Mafic facies association

The mafic facies association comprises four facies, which are restricted to the Sterling Valley Volcanics: feldspar-phyric andesite and basalt, aphyric andesite and basalt, monomictic mafic breccia and mafic mixed breccia.

3.7.1 Feldspar-phyric andesite and basalt

Feldspar-phyric andesites and basalts are exposed in the Sterling Valley and on the eastern flank of Mount Black (Fig. 3.1). Discriminating among basalts and andesites in handspecimen and thinsection is difficult. Feldspar-phyric andesites and basalts are massive, blue-green units up to ten's of metres thick, with unknown lateral extent. Lower contacts are sharp and contain sparse inclusions of silicified laminated and massive siltstone. In drill core, upper contacts with jigsaw-fit monomictic mafic breccia are sharp, irregular or gradational (Figs. 3.11 and 3.12).

This facies is characterised by 3-10%, 2-2.5 mm euhedral plagioclase, actinolite and pyroxene phenocrysts (Figs. 3.11C and 3.12B). Actinolite and pyroxene are replaced by epidote and chlorite. Plagioclase is partially replaced by sericite and epidote or chlorite. The groundmass varies from coarse-grained (~200 mm) interlocking needles of plagioclase and actinolite to fine-grained (< 50 mm) chlorite-feldspar-hematite ± epidote with hematite-filled perlitic fractures. Locally, feldspar-phyric andesites and basalts contain sericite and quartz-filled amygdales.

3.7.2 Aphyric andesite and basalt

Aphyric andesites and basalts occur along the Murchison Highway in the Sterling Valley and the southeastern shore of Lake Rosebery (Fig. 3.1). They occur as massive, strongly weathered, red or

Figure 3.11: Graphic log for drill hole STP218, which intersects a thick interval of intercalated polymictic mafic breccia, mafic volcanic sandstone and siltstone, andesitic and basaltic lavas and sills and a dacitic facies association in the Sterling Valley Volcanics. See Figure 3.4 for legend to graphic log. A. Photograph of fine-grained, aphyric basalt (STP218 32 m). B. Polymictic mafic breccia (STP218 85.5 m) containing blocky, massive, micropoikolitic, amygdaloidal and banded clasts of feldspar-phyric and aphyric dacite, andesite and basalt. These clasts have curviplanar margins, and locally preserve jigsaw-fit textures. The polymictic mafic breccia also contains irregular basaltic scoria clasts. It is poorly sorted, clast-supported and normally graded. C. Massive, coarse-grained, coherent feldspar-hornblende-phyric basalt (STP218 103.7 m). The plagioclase phenocrysts are epidote-hematite-altered. D. Photomicrograph (ppl) of polymictic mafic breccia (STP218 113.6 m). Clasts include fine-grained amygdaloidal feldspar-phyric basalt, perlitic feldspar-phyric dacite, massive aphyric andesite or basalt and basaltic scoria. The clasts are epidote- or feldspar-altered and the matrix is intensely chlorite-epidote-altered. E. Planar and diffusely laminated mafic volcanic siltstone (STP218 134.6 m).

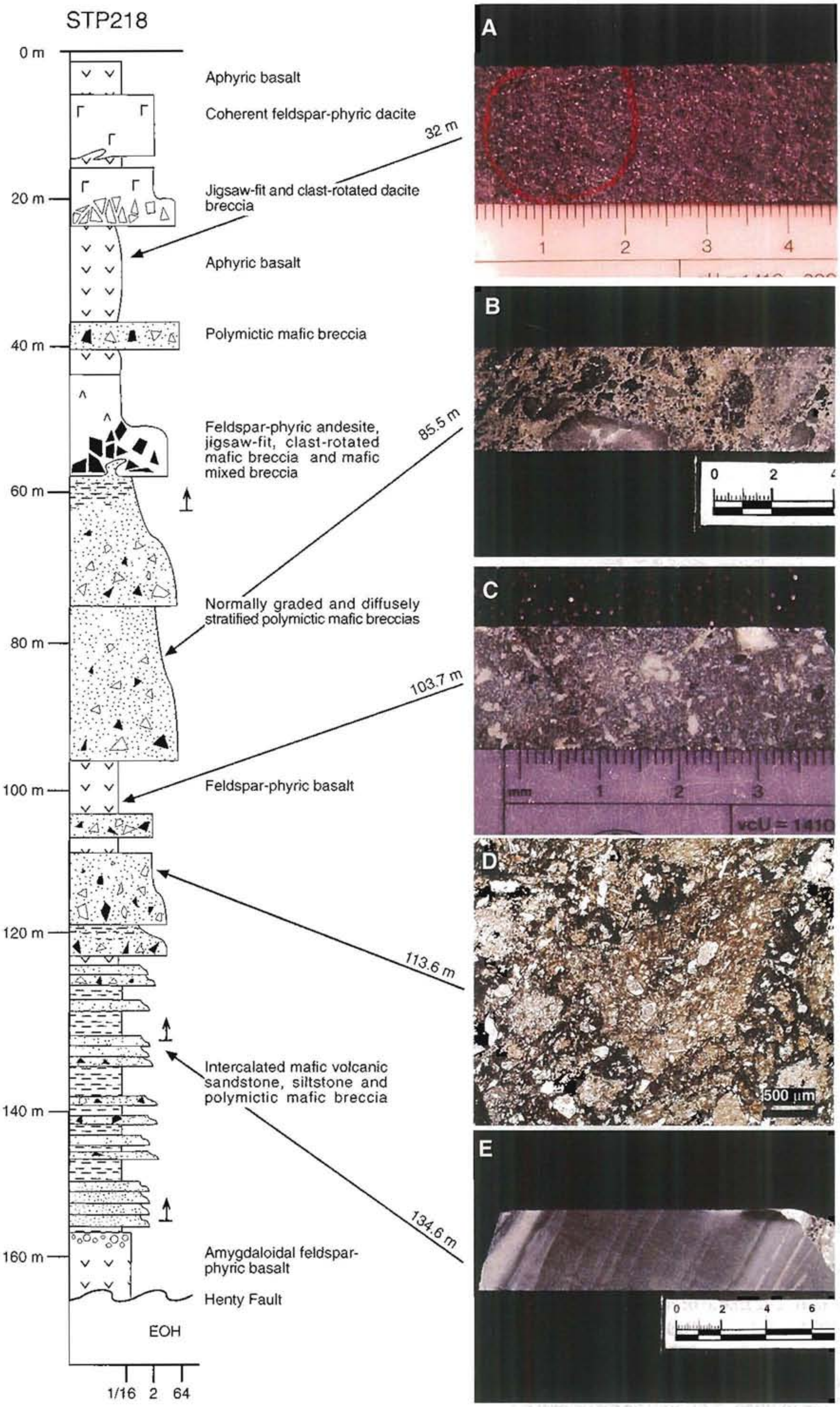
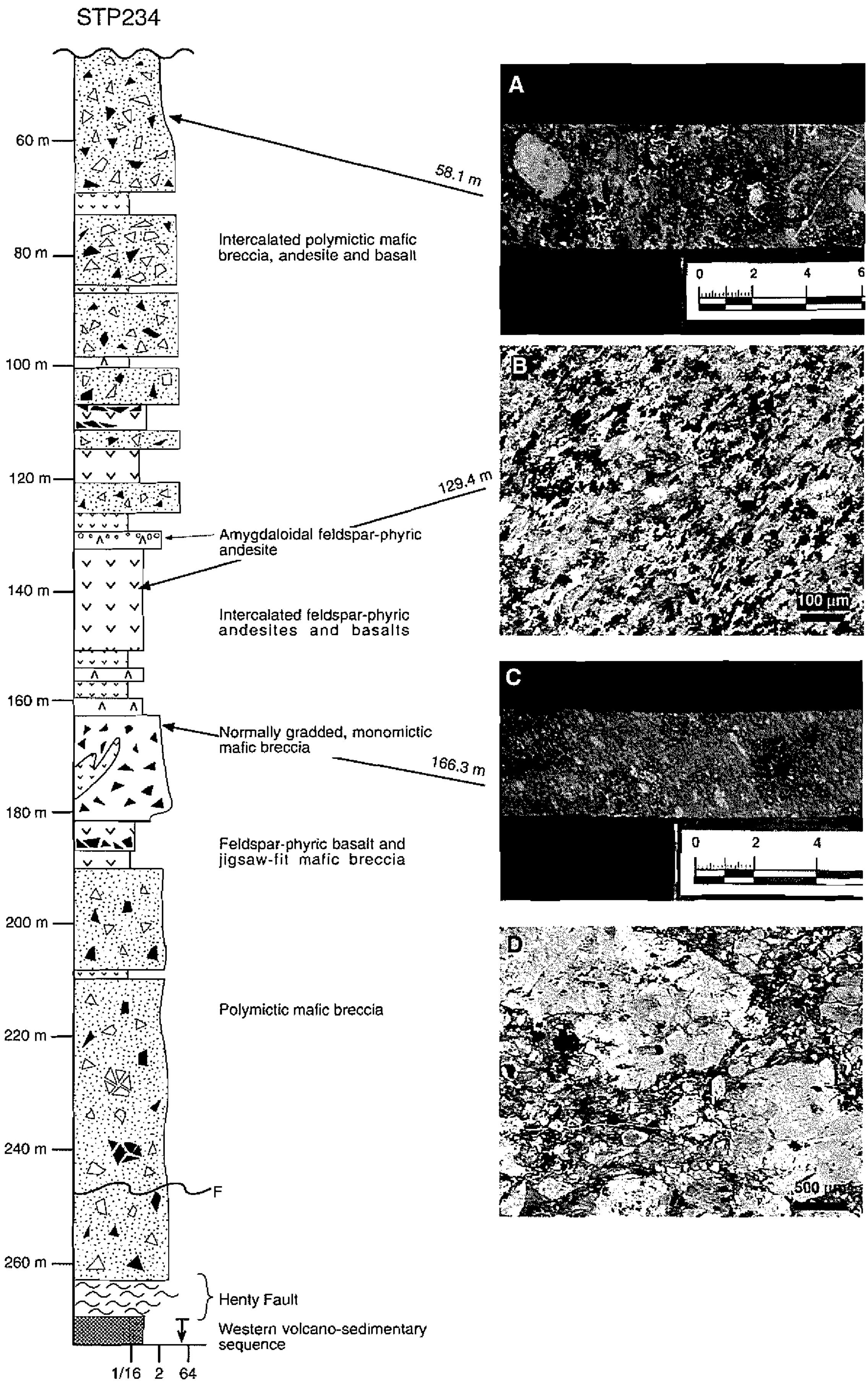

STP218
0 m
20 m
40 m
60 m
80 m
100 m
120 m
140 m
160 m
Aphyric basalt
Coherent feldspar-phyric dacite
Jigsaw-fit and clast-rotated dacite breccia
Aphyric basalt
Polymictic mafic breccia
Feldspar-phyric andesite, jigsaw-fit, clast-rotated mafic breccia and mafic mixed breccia
Normally graded and diffusely stratified polymictic mafic breccias
Feldspar-phyric basalt
Intercalated mafic volcanic sandstone, siltstone and polymictic mafic breccia
Amygdaloidal feldspar-phyric basalt
Henty Fault
EOH
1/16
2
64
32 m
85.5 m
103.7 m
113.6 m
134.6 m
A
B
C
D
E
500 µm

Figure 3.12: Graphic log for drill hole STP234, which intersects intercalated polymictic mafic breccia and andesitic and basaltic lavas and sills in the Sterling Valley Volcanics. The lavas and sills comprise coherent (feldspar-phyric andesite and basalt, and aphyric andesite and basalt) and autoclastic (monomictic mafic breccia) facies. See Figure 3.4 for legend to graphic log. A. Polymictic mafic breccia (STP234 58.1 m), which contains feldspar-phyric and feldspar-hornblende-phyric andesite and basalt, and basaltic scoria clasts. The clasts and matrix are chlorite-epidote, sericite-chlorite-hematite and feldspar-altered. B. Photomicrograph (ppl) of fine-grained, massive, aphyric basalt (STP234 129.4 m). C. Fine-grained, monomictic mafic breccia (STP234 166.3 m) composed of randomly oriented, blocky, feldspar-phyric basalt clasts. D. Photomicrograph (ppl) of monomictic mafic breccia in C.


STP234
60 m
80 m
100 m
120 m
140 m
160 m
180 m
200 m
220 m
240 m
260 m
1/16
2
64
F
Intercalated polymictic mafic breccia, andesite and basalt
Amygdaloidal feldspar-phyric andesite
Intercalated feldspar-phyric andesites and basalts
Normally gradded, monomictic mafic breccia
Feldspar-phyric basalt and jigsaw-fit mafic breccia
Polymictic mafic breccia
Henty Fault
Western volcano-sedimentary sequence
58.1 m
129.4 m
166.3 m
A
B
C
D
100 µm
500 µm
0
2
4
6

dark green outcrops. Aphyric andesites and basalts are relatively thin units, generally less than 10 m thick. Upper and lower contacts are sharp with fine-grained (<100 mm) margins (Fig. 3.11). In thinsection, interlocking laths of epidote-, chlorite- and hematite-altered plagioclase and actinolite are visible.

3.7.3 Monomictic mafic breccia facies

The monomictic mafic breccia facies is exposed in the Sterling Valley and on the east side of Mount Black (Fig. 3.1). It occurs in massive or normally graded units less than 20 m thick (Figs. 3.11 and 3.12). Lower contacts are typically diffuse or gradational with feldspar-phyric andesite or basalt and mafic mixed breccia facies. Upper contacts are either sharp or gradational with feldspar-phyric andesite or basalt.

The monomictic mafic breccia facies is generally massive, poorly sorted and clast-supported with jigsaw-fit to clast-rotated textures. Sparse intervals of monomictic mafic breccia are normally graded, from coarse breccia (4-12 cm clasts) to coarse sandstone (<5 mm clasts), and locally contain jigsaw-fit textures (Fig. 3.12, 164-182 m).

This facies is composed of angular, blocky, feldspar-phyric andesitic or basaltic perlite clasts (Figs. 3.12C and D) with curviplanar surfaces and fine-grained rims (< 1 cm thick). Clasts (2 mm to 20 cm in diameter) contain plagioclase (<10%, 1.5-2 mm), actinolite (2%, 1 mm) and pyroxene (2%, 1 mm) phenocrysts in a groundmass of feldspar, pyroxene, sericite, chlorite and magnetite. The millimetre-sized matrix is strongly chlorite-epidote altered.

3.7.4 Mafic mixed breccia facies

The mafic mixed breccia facies is associated with the margins of units of feldspar-phyric andesites and basalts (Fig. 3.11 ~60 m). It occurs in thin (< 1 m) lenses at the contact between feldspar-phyric andesite or basalt and siltstone.

This facies typically consists of sparse elongate and ragged siltstone clasts within feldspar-phyric andesite or basalt. The siltstone clasts (1 to 9 cm) are pale grey, massive and silicified. The feldspar-phyric andesite or basalt is massive or shows jigsaw-fit textures and grades into massive, coherent feldspar-phyric andesite or basalt.

3.7.5 Interpretation

The close spatial association between mineralogically identical feldspar-phyric andesite or basalt, monomictic mafic breccia and mafic clasts in the mafic mixed breccia indicates that they are genetically related. The gradation between coherent feldspar-phyric andesite or basalt and monomictic mafic breccia and the presence of jigsaw-fit textures imply that clasts formed in situ by disintegration of the feldspar-phyric andesite or basalt. The abundance of curviplanar surfaces and fine-grained rims on clasts are consistent with quench fragmentation (Pichler, 1965; Honnorez and Kirst, 1975; Yamagishi, 1987). The monomictic mafic breccia is interpreted as mafic hyaloclastite.

The gradation from coherent feldspar-phyric andesite or basalt to in situ hyaloclastite to mafic mixed breccia and the silicified and homogenous character of the siltstone clasts within the mafic mixed breccia facies are consistent with the interpretation of the mafic mixed breccia facies as peperite.

The massive character of the feldspar-phyric andesites or basalts, the geometry and gradational contacts are similar to the morphology of mafic lavas and sills. Mafic lavas in the Sterling Valley Volcanics typically comprise feldspar-phyric andesite or basalt and thick (<20 m) intervals of mafic hyaloclastite. The mafic lavas have planar conformable upper contacts. The occurrence of a few normally graded intervals of monomictic mafic breccia (mafic hyaloclastite) suggest that some quench-fragmented debris was resedimented down slope possibly by subaqueous mass flows.

Other intervals of feldspar-phyric and aphyric andesite or basalt typically have irregular or peperitic contacts and are interpreted to intrude the host volcaniclastic succession. These intrusions are generally less than 10 m thick and have unknown lateral extents, but are probably sills.

3.8 Pumice-rich facies association

The pumice-rich facies association comprises three facies: pumice breccia, pumice-rich sandstone and shard-rich siltstone. These facies occur in a discontinuous, thick (>500 m), tabular unit which extends for a minimum of 16 km along the western and northern margins of the Mount Black Volcanics (Fig. 3.1). They were intersected in deep drill holes between Rosebery and Mount Read (Figs. 3.2, 3.3 and 3.13). They are exposed north of Mount Block along the HEC transmission line track, along the Pieman Road, the Mount Black summit track and from Dallwitz to Mount Read (formerly the "Jones Creek sediments") (Fig. 3.1). Thick (>250 m) pumice breccia in drill core (EHP319) from east of Hercules appears to be on the western side of the Mount Black Fault in the Hangingwall Volcaniclastics but is unlike other Hangingwall Volcaniclastic facies and is texturally and compositionally similar to pumice breccia in the Mount Black Volcanics and the Footwall Pyroclastics (Chapter 4).

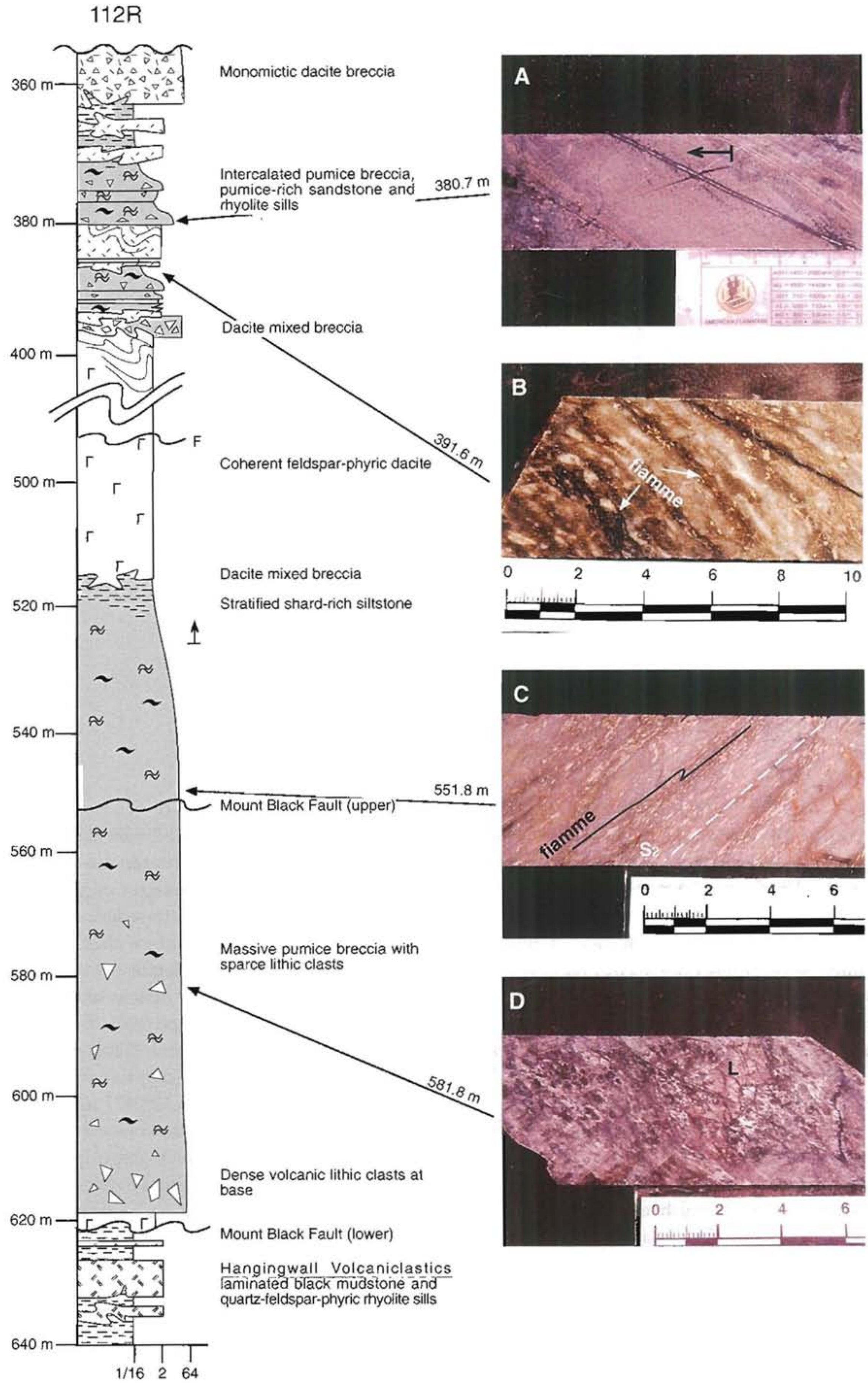
Pumice breccia is typically interbedded with or grades into pumice-rich sandstone and shard-rich siltstone (Fig. 3.13). Very rare black mudstone beds are locally intercalated with the pumice-rich sandstone and shard-rich siltstone at the top of the pumice-rich facies association. Pumice breccia beds are commonly truncated by faults and disrupted by intrusions making interpretation of emplacement processes and correlation of single beds difficult (Figs. 3.2 and 3.3).

3.8.1 Pumice breccia facies

This facies is typically mottled pink-green and contains wispy chlorite-sericite-rich fiamme (Figs. 3.13B, 3.14A and B). It occurs in thick (up to 100 m) beds that have sharp bases and are massive or have weakly developed normal grading. Single units grade from a crystal- and lithic clast-rich base through a pumice clast-rich middle section with normally graded lithic clasts to a normally graded or stratified pumice-rich sandstone or shard-rich siltstone top (Fig. 3.13).

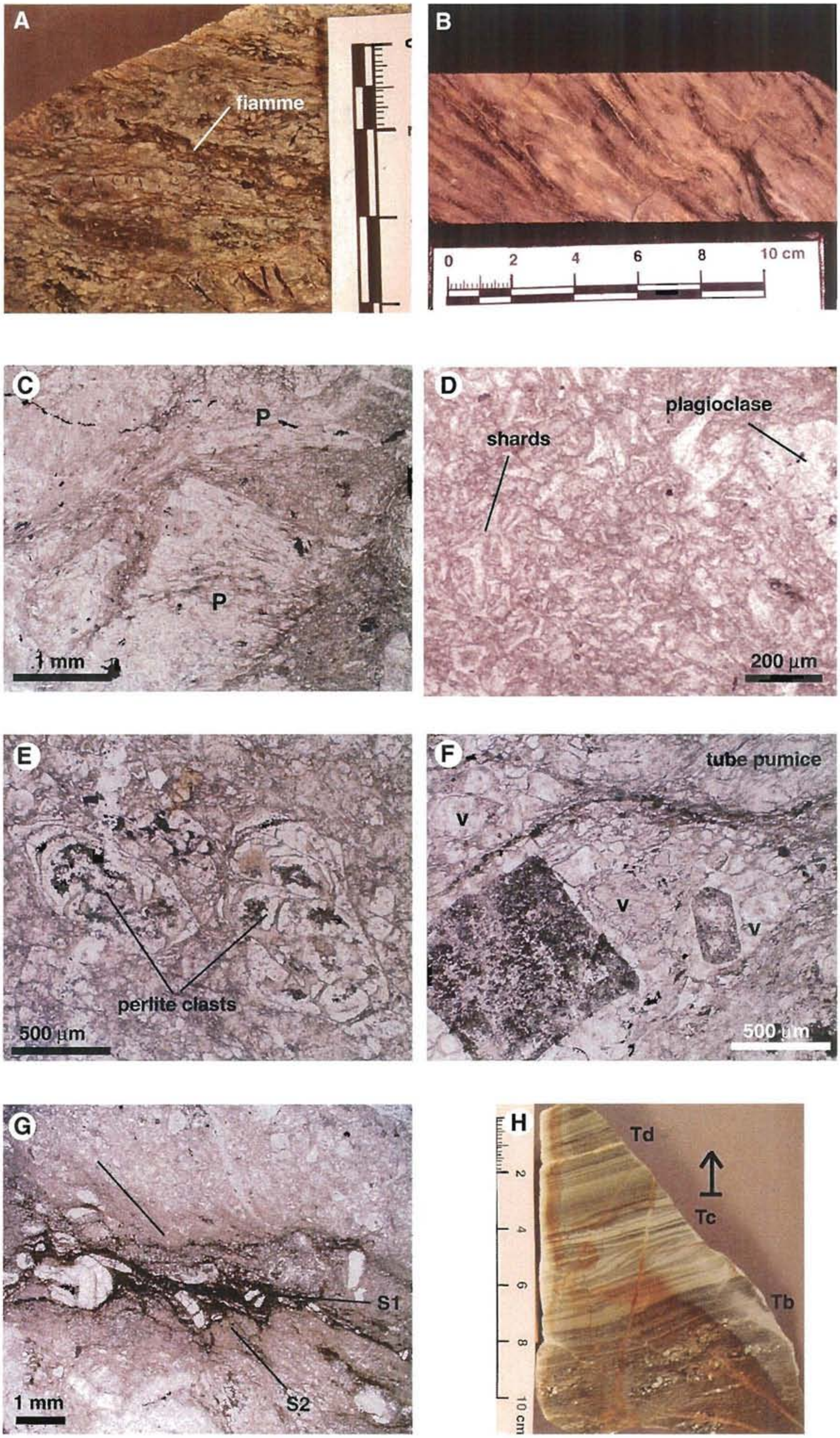
Pumice breccia facies is moderately sorted and clast-supported. It is composed of plagioclase-phyric, fibrous, tube pumice clasts (80-90%, 0.1-15 cm), plagioclase crystals and crystal fragments (5-20%, 1-2 mm), bubble-wall shards (3-20%, <0.2 mm) and sparse lithic clasts (1-5%, <10 cm) (Figs. 3.14C and D). Plagioclase phenocrysts and crystals are variably altered to albite, sericite, carbonate, chlorite, hematite, epidote and polycrystalline quartz (Fig. 3.14F). Pumice clasts are angular, ragged and blocky, whereas shards are typically cuspate or platy. The pumice clasts are both compacted and uncompacted (Fig. 3.14C). Round vesicles are preserved adjacent to plagioclase phenocrysts within

Figure 3.13: Graphic log through a thick, feldspar-phyric, pumice-rich facies association in drill hole 112R. At the base of the section (~620 m), coherent feldspar-phyric dacite is overlain by pumice breccia which contains abundant volcanic lithic clasts. The pumice breccia is massive with a normally graded, stratified shard-rich siltstone top. The shard-rich siltstone is intruded by a dacitic sill with peperitic contacts (dacite mixed breccia). The thick (110 m) pumice breccia is overlain by interbedded, normally and reversely graded pumice-rich sandstone and laminated shard-rich siltstone. See Figure 3.4 for legend to graphic log. A. Photograph of interbedded pumice-rich sandstone and shard-rich siltstone (112R 380.7 m). The facing direction is indicated by arrow. B. Pumice breccia (112R 391.6 m) containing large, sericite-rich, plagioclase-phyric fiamme. C. Photograph of quartz-sericite-altered pumice breccia (112R 551.8 m). Dark grey sericite-rich fiamme are attenuated in the strong cleavage (S_2). White plagioclase crystal fragments are visible in the sericite-altered domain. D. Large (2-4 cm), blocky, silicified and feldspar-quartz-sericite-altered volcanic lithic clasts (L) in pumice breccia (112R 581.8 m). The lithic clasts are coherent rhyolite or dacite.



112R
360 m
380 m
400 m
500 m
520 m
540 m
560 m
580 m
600 m
620 m
640 m
1/16 2 64
F
Monomictic dacite breccia
Intercalated pumice breccia, pumice-rich sandstone and rhyolite sills
Dacite mixed breccia
Coherent feldspar-phyric dacite
Dacite mixed breccia
Stratified shard-rich siltstone
Mount Black Fault (upper)
Massive pumice breccia with sparce lithic clasts
Dense volcanic lithic clasts at base
Mount Black Fault (lower)
Hangingwall Volcaniclastics
laminated black mudstone and quartz-feldspar-phyric rhyolite sills
380.7 m
391.6 m
551.8 m
581.8 m
A
B
fiamme
0 2 4 6 8 10
C
fiamme
S2
0 2 4 6
D
L
0 2 4 6

Figure 3.14: Handspecimen and thinsection photographs of pumice breccia, pumice-rich sandstone and shard-rich siltstone in the Mount Black Volcanics. A. Pumice breccia (sample R17) with abundant aligned, feldspar-phyric, sericite-rich fiamme surrounded by pale feldspar-quartz-sericite-altered domains. The fiamme have irregular shapes and delicate feathery terminations. B. Fine-grained, pumice breccia (EHP319 489 m) with dark, sericite fiamme enclosed in pink feldspar-quartz-sericite-altered domains. C. Photomicrograph (ppl) of blocky and ragged, uncompacted, tube pumice clasts (p) in pumice breccia (49R 1020'). The matrix is feldspar-quartz-sericite-altered with disseminated sericite-hematite and carbonate. Vesicles in the pumice clasts are coated with thin films of sericite and filled with albite. Vesicle walls are composed of feldspar-quartz-sericite. D. Photomicrograph (ppl) of bubble wall shards and albite-altered plagioclase crystal fragments in pumice-rich sandstone (120R 613m). The feldspar-quartz-altered shards are coated in thin films of sericite and surrounded by fine feldspar, quartz and sericite. E. Photomicrograph (ppl) of perlite clasts in pumice breccia (120R 477 m). Thin films of sericite, which is partially replaced by chlorite, define perlitic fractures in these blocky clasts. The perlite kernels are feldspar-quartz-sericite- and chlorite-altered. F. Photomicrograph (ppl) of tube and round vesicle pumice in pumice breccia (EHP319 538 m). The uncompacted pumice clasts preserve vesicles (v) which are coated with thin films of sericite. The bubble walls have been replaced by and vesicles infilled by albite. Plagioclase phenocrysts in the pumice clasts are albite-hematite-altered. G. Photomicrograph (ppl) of the two dominant foliations in pumice breccia (120R 727 m). S_1 is the compaction foliation defined by the dark sericite-chlorite fiamme and sericite-hematite stylolites. S_2 is the regional cleavage defined by the strong alignment of sericite in the matrix. H. Interbedded pumice-rich sandstone and shard-rich siltstone (sample MX) containing bedforms typical of the Tb, Tc and Td divisions of the Bouma sequence (cf. Bouma, 1962). This sample includes graded bedding, diffuse laminations, cross-laminations, and planar laminations. Feldspar-phyric chlorite-sericite-rich fiamme in the graded sandstone are interpreted to represent compacted and altered pumice clasts.


A
fiamme
B
0
2
4
6
8
10 cm
C
P
P
1 mm
D
plagioclase
shards
200 µm
E
perlite clasts
500 µm
F
tube pumice
v
v
v
500 µm
G
S1
S2
1 mm
H
Td
Tc
Tb
2
4
6
8
10 cm

the uncompacted pumice clasts (Fig. 3.14F). The vesicles are coated with a thin film of sericite or carbonate and filled with albite. Vesicle walls in the pumice clasts and shards are feldspar or a mosaic of feldspar and quartz. Lithic clasts occur near the base of beds, decreasing in size and abundance upward (Fig. 3.13). The lithic clasts include: porphyritic, perlitic (Fig. 3.14E), spherulitic and flow-banded to massive rhyolite, as well as non-volcanic mudstone clasts. The volcanic lithic clasts are angular, blocky and equant, whereas mudstone clasts are typically elongate and ragged.

In the pumice breccia facies, 1-5 cm long, dark green sericite or chlorite-sericite-rich fiamme are aligned roughly parallel to regional bedding and are enclosed in pale domains of feldspar-quartz-altered pumice clasts (Figs. 3.14A and B). These fiamme are porphyritic (plagioclase), with delicate feathery terminations, and locally preserved flattened tube pumice textures, indicating that they are altered compacted pumice clasts (Chapter 6). The abundance of the fiamme in the pumice breccia facies results in a foliation that resembles eutaxitic texture in welded pyroclastic deposits (cf. Allen, 1988).

3.8.2 Pumice-rich sandstone facies

Pumice-rich sandstone beds up to 2 m thick, have sharp basal contacts, are massive, graded or diffusely stratified and are texturally identical to the finely stratified tops of the beds of the pumice breccia facies. Grading is commonly normal although reversely graded beds also occur (Fig. 3.13, ~375 m).

The pumice-rich sandstone facies is well sorted, clast-supported and comprises tube pumice clasts (50-60%, 0.5-3 mm), bubble-wall shards (30%, 0.2 mm), plagioclase crystal fragments (10-20%, 1 mm) and green wispy, chlorite-sericite-rich fiamme (3-5 mm) in a matrix of feldspar-quartz-sericite (fig. 3.14D). Pumice clasts are irregular, ragged and elongate. The originally glassy shards and pumice clasts have been replaced by feldspar, feldspar-quartz-sericite, calcite or chlorite-sericite-hematite. Plagioclase crystal fragments have been partially to completely replaced by sericite, calcite or feldspar (albite).

3.8.3 Shard-rich siltstone facies

The shard-rich siltstone facies is siliceous, pale grey or green, laminated (averaging 3 mm in thickness) and interbedded with pumice-rich sandstone (Fig. 3.14H). Laminations are diffuse to distinct, planar and internally graded and cross-laminated. Convolute folds, slumps, syn-depositional faults (up to 10 cm) and local scours infilled by pumice-rich sandstone are common.

Shard-rich siltstone facies is well sorted and comprises bubble-wall and platy shards (80%, <0.5 mm), feldspar crystal fragments (10-20%, 0.1-0.3 mm) and sparse chlorite-sericite-rich fiamme (<1 mm) in a matrix of sericite, quartz and feldspar. The shards are composed of feldspar or feldspar and quartz and partially altered to calcite and sericite. Feldspar crystal fragments have been partially to completely altered to sericite, calcite or feldspar. The chlorite-sericite-rich fiamme contain euhedral plagioclase crystals and commonly have a chlorite-sericite-hematite stylolitic foliation (Fig. 3.14H).

3.8.4 Interpretation

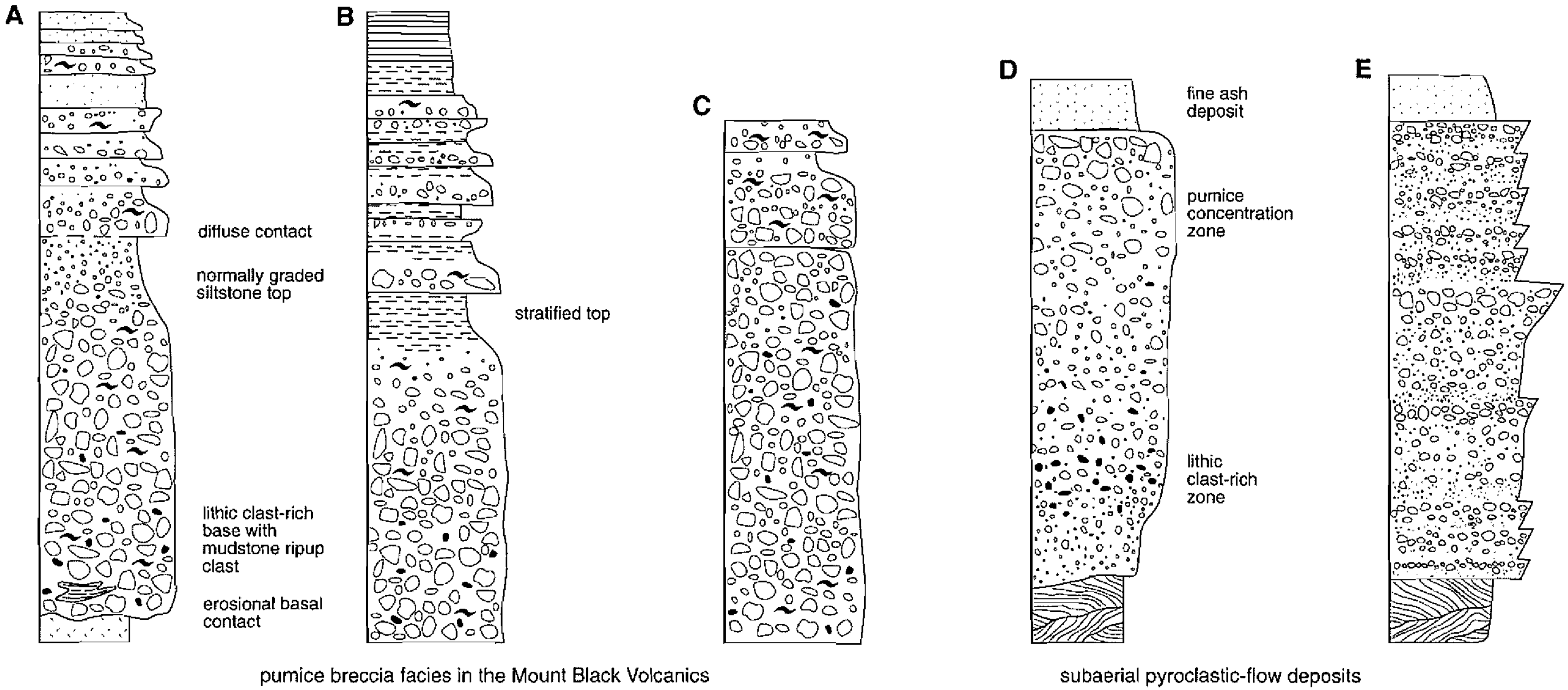
The pumice-rich facies association is essentially composed of juvenile pyroclasts (angular and ragged, highly vesicular tube pumice clasts, thin-walled shards and crystal fragments) that were produced by an explosive felsic eruption (cf. Dimroth and Yamagishi, 1987). The thickness (>500 m) and extensive (>16 km) nature of this association indicate a large-volume eruption or eruptions. Calculations of the minimum volume of the pumice-rich facies association, based on the thickness, lateral extent and estimated minimum width (the distance between fold repetitions ~3 km) of the facies association, suggest that the bulk volume was greater than 24 km^3. Considering that the lateral extent is significantly greater than the estimated width and that the thickness is the minimum diagenetically compacted thickness, the original volume of pumiceous debris was probably much greater.

In the pumice breccia facies, the textural preservation of clasts, moderate sorting, thick bedding, tabular geometry, and weakly developed grading are consistent with rapid deposition, either during or soon after eruption, from a high-concentration mass flows (cf. Branney and Kokelaar, 1992; Smith, 1986). The pumice breccia facies has similarities with subaerial ignimbrites and several exposures of pumice breccia in the Mount Black Volcanics have previously been described as welded ignimbrite (Green et al., 1981; Corbett, 1989). Both the pumice breccia facies and subaerial ignimbrites are composed of large volumes of pumice clasts, shards, crystal fragments and subordinate lithic clasts. However, pumice breccia units in the Mount Black Volcanics have different internal organisation and bedforms from subaerial ignimbrites (Fig. 3.15) (cf. Sparks et al., 1973; Sparks, 1976). They are better sorted, relatively depleted in ash, do not generally show reversely graded pumice clasts within beds and lack evidence of hot emplacement, such as welding, thermal oxidation, columnar joints, baked contacts, vapour-phase crystallisation or degassing structures. Although chlorite-sericite fiamme are present in the pumice-rich facies association, uncompacted pumice clasts and shards are present in feldspar-altered domains. These shards are randomly oriented, whereas glass shards in welded ignimbrites are flattened and aligned plastically as a result of compaction while the shards were hot (Smith, 1960). Thus, pumice breccia facies was originally non-welded and the chlorite-sericite fiamme are interpreted to represent originally glassy fragments that were altered and flattened during diagenesis and lithification (Chapter 6) (cf. Allen, 1990a unpub.; Allen and Cas, 1990 unpub.; Branney and Sparks, 1990; McPhie et al., 1993; Dimroth and Yamagishi, 1987; Niem, 1977).

Massive pumice breccia beds with normally graded and stratified tops suggest that they were deposited from water-supported gravity flows, most probably high-concentration density currents or debris flows (Fig. 3.16) (cf. Niem, 1977; Lowe, 1982; Cas and Wright, 1991; Branney and Kokelaar, 1992). The increased abundance of dense lithic clasts towards the base of beds implies density sorting. Mudstone clasts and local scours suggest that in some instances, the gravity flows were erosive (Fig. 3.15A). Thick massive beds require flows that are sustained at relatively constant discharge for long periods, such as might be expected during a large-magnitude explosive eruption (Niem, 1977; Kneller, 1995).

Sedimentary structures within the interbedded pumice-rich sandstone and shard-rich siltstone are consistent with the interpretation of water-settled fallout from suspension and turbidites, sourced either directly from eruption or from the trailing ash cloud associated with high-concentration density flows (cf. Fig. 3.16A, B and F) (cf. Bouma, 1962; Selley, 1970; Dimroth and Yamagishi, 1987; Lowe, 1982).

The massive to normally graded pumice-rich sandstone beds (S3, Fig. 3.16F) and reversely graded pumice breccia beds (S2, Fig. 3.16F) may result from the deposition from high-concentration



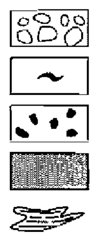


Figure 3.15: Comparison of bedforms and grainsize variation between pumice breccia, pumice-rich sandstone and shard-rich siltstone deposits in the Mount Black Volcanics and primary pyroclastic-flow deposits (ignimbrite). A. A doubly graded interval of interbedded pumice breccia, pumice-rich sandstone and shard-rich siltstone in the Mount Black Volcanics, between 20-150 m thick. Based on intersections in drill holes 60R, 73R, 80R and EHP319. B. Massive to normally graded beds with diffusely stratified siltstone tops. This succession is between 60-150 m thick. Based on intervals in drill holes 112R, 120R and 128R. C. Massive pumice breccia beds between 120-200 m thick. Based on intersections in drill holes 78R and 120R. D. Graphic log through a massive interval of a subaerial non-welded pyroclastic-flow deposit. After Sparks et al. (1973) and Sheridan (1979). E. Subaerial non-welded stratified pyroclastic-flow deposit (after McPhie et al., 1993).

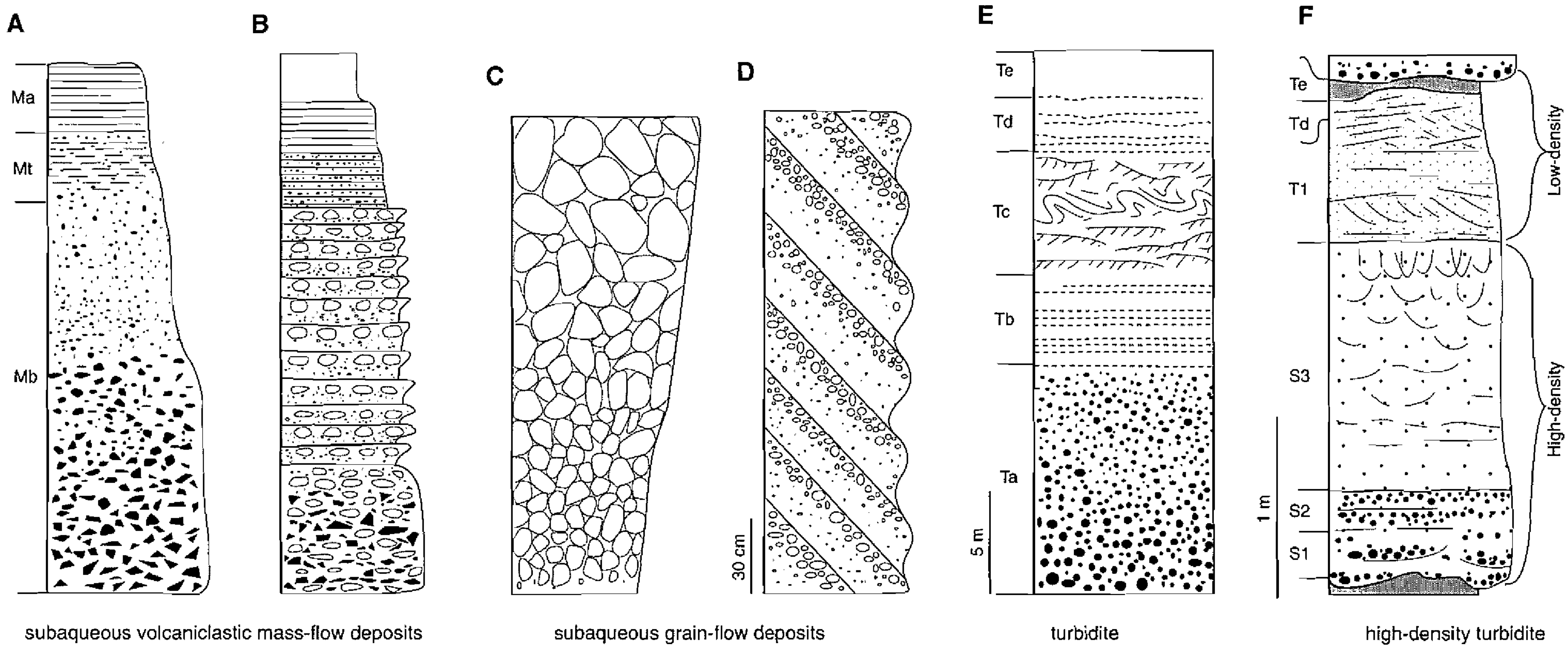


Figure 3.16: Graphic logs comparing bedforms and grainsize variations between subaqueous volcaniclastic mass-flow deposits, grain-flow deposits and turbidites. See Figure 3.15 for legend. A. Massive subaqueous volcaniclastic mass-flow deposits, showing divisions for basal debris flow (Mb), transitional zone (Mt) and water-settled fallout (Ma). Succession si between 12-150 m thick. Based on Yamada (1984), Allen (1991 unpub.) and Cashman and Fiske (1991). B. Doubly graded, 20- to 60 m-thick subaqueous volcaniclastic mass-flow units (after Fiske and Matsuda, 1964). C. Thinly bedded grain-flow deposits with characteristic reversely graded beds and steep primary dip. Modified from Lowe (1982). D. Thick, reversely graded, clast-supported, density modified grain-flow deposit. Modified from Lowe (1976 and 1982). E. Low-density turbidite, showing the ideal sequence of structures (Bouma divisions Ta to Te) (after Bouma, 1962). F. Sandy high-density turbidite, showing deposits from the high density stage (divisions S1-3) and from the residual low density stage (divisions Tt-e). Modified from Lowe (1982).

density currents, grain flows or suspension from the water column (Fig 3.16C and D) (cf. Lowe, 1976; Lowe, 1982). In contrast, cross-laminated siltstone and sandstone indicate tractional sedimentation (division Tb-d, Fig. 3.16E) from turbidity currents (Bouma, 1962). Turbidites in the Mount Black Volcanics rarely show all the divisions of the classical Bouma sequence (Fig. 3.14H). Massive sandstone beds with scours at the base (Ta or S3), laminated sandstone (Tb), cross-laminated sandstone (Tc) and laminated siltstone (Td) are common.

Laminated shard-rich siltstone (division Td) was probably deposited by settling of suspended ash and pumice clasts through the water column. Feldspar-phyric chlorite-sericite fiamme in the sandstone and siltstone facies are interpreted to represent compacted and altered pumice clasts that were initially buoyant but became water-logged and settled from suspension in the water column. The common association of laminated shard-rich siltstone at the top of normally graded pumice breccia beds, interpreted to be emplaced by mass-flow processes, suggests that deposition was by settling of suspended ash and pumice clasts at the waning phases of density currents. However, parallel laminae produced by water-settled fall can not always be distinguished from laminae produced by deposition from low-density turbidity current (Kokelaar et al., 1985).

The unmodified angular nature of pumice clasts, preservation of shards, compositionally homogeneous nature of the units, absence of other clast types in these facies and lack of other facies interbedded with the pumice-rich facies association suggest that this facies association is syn-eruptive (cf. McPhie et al., 1993) and that no significant reworking occurred (cf. Niem, 1977). The thickness of the pumice-rich facies association (>500 m) and lack of other facies intercalated with the association imply that these are proximal facies that were deposited quickly on the seafloor.

Hot pumice clasts would have initially been buoyant in the water column, however rapid quenching, ingestion of seawater and condensation of gases within the vesicles would have caused clasts to sink (cf. Whitham and Sparks, 1986; Kato, 1987; Fiske et al., in press). Deposition of water-logged pumice clasts, shards and crystals may have originally been by a combination of water-settled fall and water-supported mass flow (cf. Fiske et al., in press). Subsequently pumice clasts and ash, which had remained buoyant, settled from suspension.

3.9 Pumice-lithic clast-rich facies association

The pumice-lithic clast-rich facies association comprises two facies: pumice-lithic clast-rich breccia and sandstone. These facies are confined to the western side of the Mount Black Volcanics, exposed between Pieman Road and Mount Read (Fig. 3.1).

3.9.1 Pumice-lithic clast-rich breccia

Pumice-lithic clast-rich breccia facies occurs in 20- to 250 m-thick units which extend laterally up to 1500 m. Pumice-lithic clast-rich breccia units are interbedded with and grade into pumice-lithic clast-rich sandstone units. Single beds of pumice-lithic clast-rich breccia are between 2-80 m thick and are massive to normally graded (Fig. 3.17). A few beds have diffusely laminated tops. Basal contacts include: scours, channels and flames of underlying finer-grained units. Upper contacts are sharp and irregular or grade into pumice-lithic clast-rich sandstone.

Pumice-lithic clast-rich breccia facies is composed of tube and round vesicle pumice clasts (30-80%, 0.2-10 cm), lithic clasts (10-60%, 0.2-6 cm), plagioclase crystal fragments (3-20%, 1-2 mm), and chlorite-sericite fiamme. The lithic clast population is polymictic and varies among units. Lithic clasts may include: perlitic plagioclase-phyric and aphyric rhyolite, flow-banded plagioclase-phyric rhyolite, spherulitic and micropoikolitic rhyolite or dacite (Fig. 3.18). Extremely sparse, siliceous siltstone clasts also occur (78R 101.5m). Some samples also contain well-preserved bubble-wall shards (<10%, 0.1-0.2 mm).

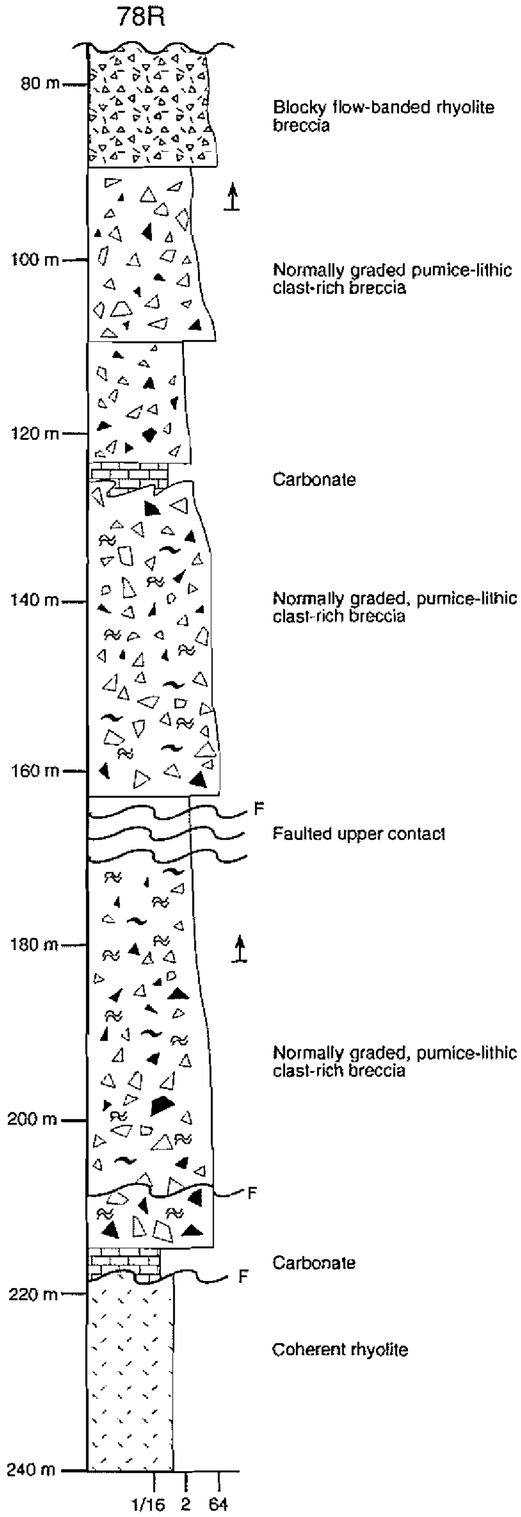
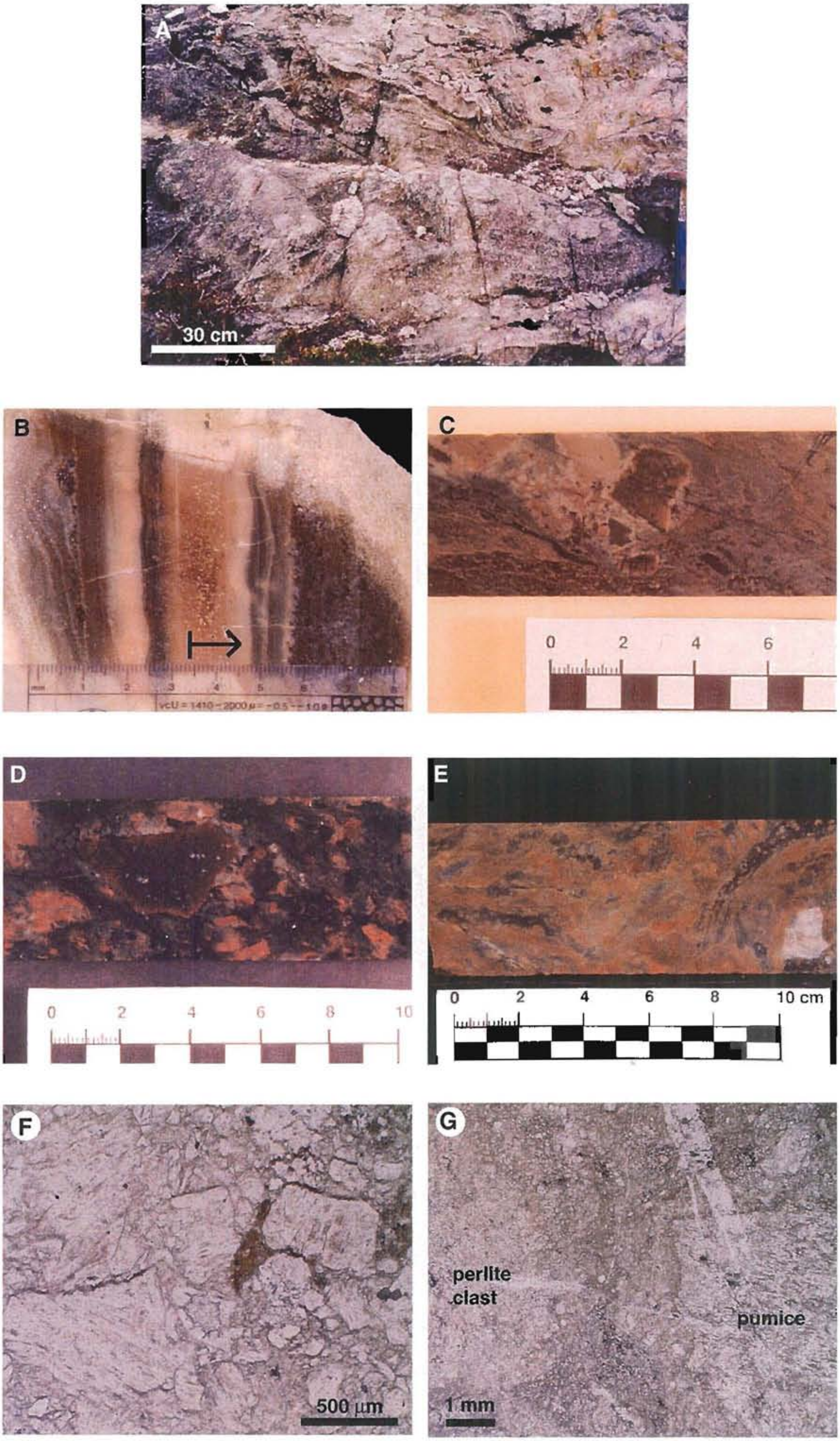


Figure 3.17: Graphic log through a number of normally graded, pumice-lithic clast-rich breccia beds in drill hole 78R. Contacts are planar and conformable or faulted. See Figure 3.4 for legend to graphic log.

Figure 3.18: Outcrop, handspecimen and thinsection photographs of pumice-lithic clast-rich breccia and sandstone in the Mount Black Volcanics. A. Outcrop photograph of scouring and channel fill in interbedded pumice-lithic clast-rich breccia and sandstone on the eastern flank of Mount Read. Bedding is discontinuous and lensoidal. B. Handspecimen (sample MR9) from outcrop viewed in A. Interbedded green pumice-lithic clast-rich sandstone and pink siltstone. Beds are internally graded with planar bases which truncate the tops of underlying beds. Way-up is indicated by the arrow. C. Pumice-lithic clast-rich breccia containing angular, blocky, rhyolite clasts, tube pumice clasts and wispy sericite-rich fiamme (128R 189 m). The rhyolite clasts are feldspar-phyric and have abundant curviplanar margins. They are intensely feldspar-quartz-sericite- and chlorite-sericite-altered, with pink feldspar haloes surrounding many of the rhyolite clasts. D. Strongly chlorite-sericite- and feldspar-quartz-sericite-altered pumice-lithic clast-rich breccia (120R 226 m). Abundant dense, feldspar-phyric, massive rhyolite clasts with curviplanar margins. E. Strongly chlorite-sericite- and feldspar-quartz-sericite-altered pumice-lithic clast-rich breccia (78R 174 m). F. Photomicrograph (ppl) of blocky, uncompacted, tube pumice clasts in pumice-lithic clast-rich breccia (120R 148.5 m). The tube vesicles are coated in a film of sericite and filled with albite. Vesicle walls are composed of feldspar-quartz-sericite. The matrix is composed of feldspar, quartz and sericite, and is overprinted by patchy biotite. G. Photomicrograph (ppl) of a feldspar-phyric, pumice-lithic clast-rich breccia (120R 447 m) composed of blocky uncompacted tube pumice and perlite clasts.


A
30 cm
B
C
0
2
4
6
D
0
2
4
6
8
10
E
0
2
4
6
8
10 cm
F
500 μm
G
perlite clast
pumice
1 mm

Pumice clasts are plagioclase-phyric, ragged and have equant or elongate shapes (Fig. 3.18F). Pumice clasts are both compacted and uncompacted. Flow-banded and banded perlite clasts are typically blocky or platy. Other rhyolite and dacite clasts are blocky, equant and angular to subangular with planar or curviplanar edges (Figs. 3.18C and D). Chlorite-sericite and chlorite-magnetite feldspar-phyric fiamme up to 20 cm in length, blocky chlorite-altered domains with curviplanar margins and chlorite-sericite-hematite stylolites are common (Figs. 3.18C and E).

Beds are poorly sorted and clast-supported. Clasts have random orientations, although local jigsaw-fit domains exist. The sand sized matrix is composed of feldspar-quartz-sericite.

A diverse range of alteration facies occurs in the pumice-lithic clast-rich breccia facies. Dense rhyolitic and dacitic lithic clasts typically contain concentrically zoned alteration facies (feldspar-quartz-sericite, chlorite-sericite) and are enclosed in a pink halo of feldspar-quartz-sericite alteration (Fig. 3.18C). Flow-banded clasts comprise alternate green chlorite-sericite-altered and pink feldspar-quartz-sericite-altered flow-bands. Uncompacted pumice clasts are altered to pink or white feldspar (Fig. 3.18G). Plagioclase crystals and crystal fragments are strongly altered to sericite, calcite or feldspar.

3.9.2 Pumice-lithic clast-rich sandstone
Pumice-lithic clast-rich sandstone facies occurs in thin (<1 m) well sorted, clast-supported, normally graded beds. Bedding is discontinuous, lensoidal and channellised (Figs. 3.18A and B). Internally the beds are typically massive or normally graded, with either gradational or sharp contacts.

Pumice-lithic clast-rich sandstone facies is composed of tube pumice clasts (50-80%, < 8 mm), lithic clasts (10-30%, 2-4 mm) and plagioclase crystal fragments (20%, <2 mm). Lithic clasts may include: perlitic rhyolite and micropoikolitic rhyolite or dacite (Fig. 3.18). Pumice clasts are ragged with equant shapes and lithic clasts are blocky, equant and angular to subangular with planar or curviplanar edges. Pumice and lithic clasts have been replaced by feldspar-quartz-sericite, calcite-sericite and chlorite-sericite. Plagioclase crystals and crystal fragments have been altered to sericite, calcite or feldspar.

3.9.3 Interpretation
Clasts in the pumice-lithic clast-rich breccia facies have similar compositions and textures to clasts in the pumice breccia facies, monomictic rhyolite breccia facies and monomictic dacite breccia facies, and with coherent rhyolite and dacite. Equant dense volcanic clasts with planar and curviplanar margins and slab-shaped flow-banded rhyolite clasts are consistent with fragmentation by quenching and autobrecciation respectively (cf. Yamagishi, 1987; McPhie et al., 1993). This suggests that at least the dense volcanic clasts in the pumice-lithic clast-rich breccia facies were sourced from unlithified hyaloclastite or autobreccia. Local jigsaw-fit textures are consistent with the disintegration of larger, fractured, possibly hot, clasts during transport. The occurrence of pumiceous hyaloclastite at the margins of highly vesicular rhyolitic lavas (Chapter 5) indicates that pumice clasts may have been derived from the pumiceous hyaloclastite carapace associated with lavas. This is consistent with the interpretation that clasts in the pumice-lithic clast-rich facies association were derived directly from lavas or domes with an autoclastic carapace but does not exclude the possibility that clasts may have been derived from unconsolidated deposits of hyaloclastite, autobreccia and pumice breccia.

Thick massive beds, and abundant delicate and angular pumice clasts suggest that the pumice-lithic clast-rich breccia and sandstone facies were emplaced rapidly after eruption and that little or no reworking occurred. The absence of shards in most pumice-lithic clast-rich breccias may be due to elutriation of fine particles during transport or reflect a shard-poor source, such as autobreccia.

Poorly sorted, thick (20-250 m), massive beds of pumice-lithic clast-rich breccia facies indicate deposition from subaqueous gravity flows, probably debris flows or density-modified grain flows. Normally graded beds were deposited by debris flows or high-concentration density currents (cf. Lowe, 1982). Thin (<1 m), well sorted, discontinuous, lensoidal and channellised beds of pumice-lithic clast-rich sandstone are consistent with deposition from high-concentration sandy turbidity currents or debris flows. The presence of well developed normal grading and tractional structures (including planar laminations, cross stratification and locally erosive contacts) in the pumice-lithic clast-rich sandstone facies suggests that deposition was from sandy high-concentration turbidity currents (S1) (cf. Lowe, 1982).

These debris flows and turbidity currents probably originated as slumps or slides that were generated by slope failure resulting from subaqueous eruptions, continued emplacement of lava, the shallow intrusion of magma up-doming substrata, dome-related steam explosions, volcano-tectonic earthquakes or by movement along syn-depositional faults.

3.10 Crystal-rich sandstone facies

Crystal-rich sandstone units are common in other parts of the Mount Read Volcanics, specifically the White Spur Formation (Corbett, 1992; Corbett and Lees, 1987; McPhie and Allen, 1992a) and the Tyndall Group (White and McPhie, 1996), but are rare in the Mount Black Volcanics. Crystal-rich sandstone units are thin (< 4 m thick), massive and tabular with a minimum lateral extent of several kilometres (Fig. 3.1). Beds of crystal-rich sandstone have sharp planar basal contacts, are internally massive and some have normally graded tops.

The crystal-rich sandstone facies is moderately well sorted, clast-supported and composed of subangular crystal (30-60%, 0.5-2.5 mm) and rock fragments (40-60 %, 1-2 mm) (Fig. 3.19). The crystal fragments include: feldspars (20%, 0.5-2 mm; plagioclase, microcline and anorthoclase), quartz (10-40%, 1-2.5 mm), detrital muscovite (<1%, 1 mm), rare zircons (<1%) and abundant Fe-oxides (5-10%, 0.1 mm; hematite and magnetite). The plagioclase crystal fragments often have thin K-feldspar or albite overgrowths and are sericite- or epidote-altered. The quartz crystal fragments include: clear volcanic quartz with abundant fluid inclusions, metamorphic quartz with undulose extinction and polycrystalline (vein) quartz. In handspecimen, crystal fragments are unevenly distributed in a fine-grained chlorite-sericite-altered matrix. Rock fragments include: chert, aphyric basalt, dolerite, plagioclase-phyric tube pumice, perlitic dacite and foliated muscovite-rich meta-siltstone clasts.

3.10.1 Interpretation

The distinctive crystal-rich nature and abundance of quartz grains makes this facies unique in the Mount Black and Sterling Valley Volcanics where quartz-feldspar-phyric facies are rare. This suggests that the source for the abundant volcanic quartz crystal fragments was outside the northern Central

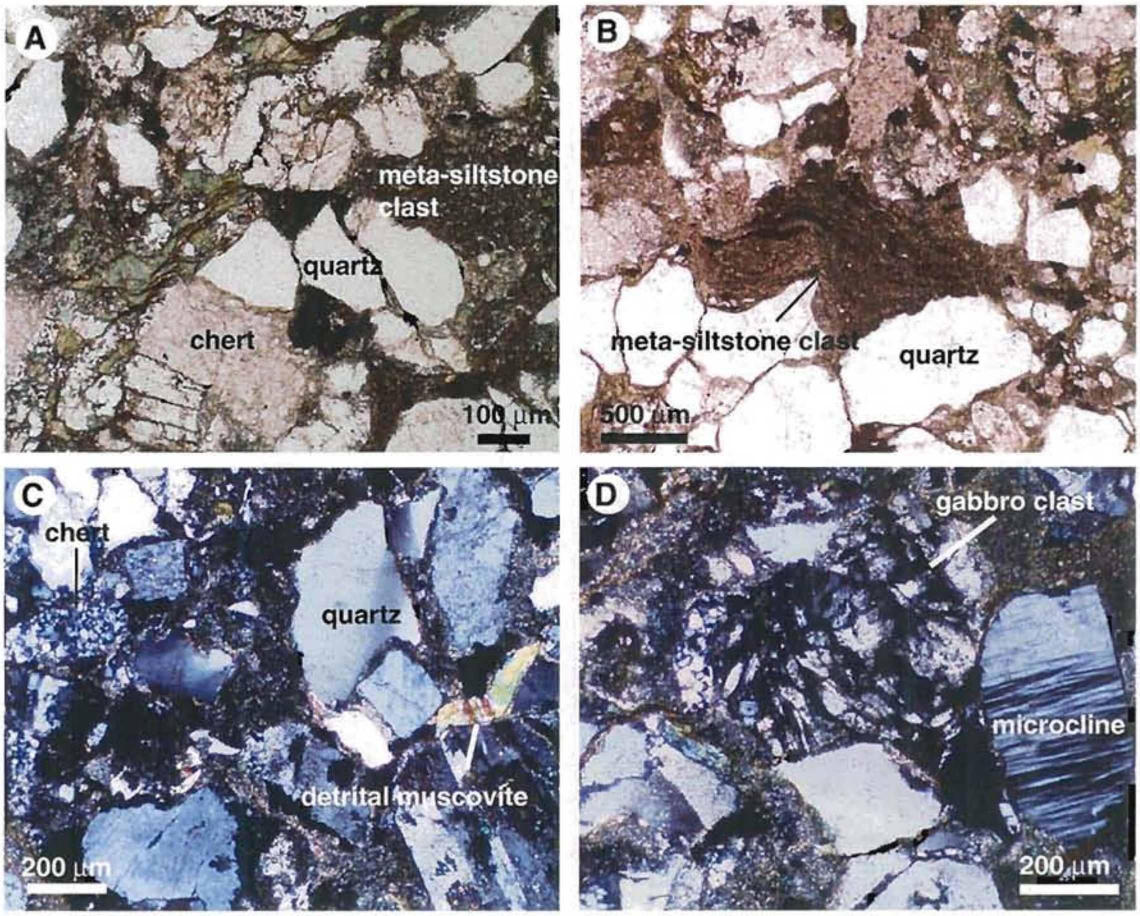


Figure 3.19: Photomicrographs (A. and B. ppl, C and D xn) of crystal-rich sandstone in the Mount Black Volcanics (M60). This crystal-rich sandstone contains abundant subangular, strongly altered plagioclase, microcline, and anorthoclase crystal fragments, clear quartz crystal fragments, iron oxide grains, subordinate detrital muscovite grains (C), and lithic clasts. The lithic clasts include: chert (A and C), meta-siltstone (A and B), fine-grained basalt and dolerite (D). The matrix is strongly chlorite-sericite-altered.

Volcanic Complex. There are a number of possible mechanism for generating abundant volcanic quartz and feldspar crystal fragments. These include: (1) weathering and erosion of feldspar- and quartz-rich deposits; (2) explosive eruption of quartz-feldspar-phyric magma that releases crystal fragments; and (3) quench fragmentation of quartz-feldspar-phyric magma. As the feldspar and quartz crystal fragments in this facies are angular, weathering and erosion are not considered to have been a likely mechanism to produce the crystal fragments. Quench fragmentation is inconsistent with the volume of this facies, the abundance of free crystal fragments and the absence of spatially associated coherent quartz-feldspar-phyric facies. Explosive eruption of quartz-feldspar-phyric magma is the most plausible interpretation for the generation of the abundant crystal fragments. The implication is that this facies is sourced from a distal pyroclastic deposit or explosive eruption outside the immediate basin. Volcanic and sedimentary processes may have depleted the original deposit or flow of fine ash, thus enhancing the crystal concentration.

Metamorphic and vein quartz were probably derived from the Precambrian basement. A Precambrian basement source is also supported by the detrital muscovite grains and meta-siltstone clasts. Abundant hematite and magnetite grains suggest a mafic or ultra mafic source, such as the Crimson Creek Formation. Chert fragments may also be derived from this Early Cambrian sedimentary succession. In contrast, rock fragments such as pumice clasts, perlitic dacite, aphyric basalt and dolerite may have been sourced locally from the Mount Read Volcanics, possibly from the Mount Black and Sterling Valley Volcanics.

Thus the crystal-rich sandstone has a mixed provenance which includes Precambrian basement, Early Cambrian sedimentary successions (possibly the Crimson Creek Formation), the Mount Read Volcanics (possibly the Mount Black and Sterling Valley Volcanics) and an unknown source for the abundant volcanic quartz crystal fragments.

The subangular nature of the crystal fragments and clasts suggests that reworking was minimal. Massive, thick (4 m) beds of crystal-rich sandstone are typical of deposits from high-concentration density currents, either turbidity currents or sandy debris flows (Lowe, 1982; Cas, 1978; Kneller and Branney, 1995).

3.11 Polymictic volcanic facies association

The polymictic volcanic facies association is limited to the Sterling Valley area and includes three facies: polymictic mafic breccia, mafic volcanic sandstone and siltstone. This facies association is intercalated with dacite facies association (coherent feldspar-phyric dacite, monomictic dacite breccia, dacite mixed breccia) and mafic facies association (feldspar-phyric andesite and basalt, aphyric andesite and basalt, monomictic mafic breccia, mafic mixed breccia).

3.11.1 Polymictic mafic breccia facies

Polymictic mafic breccia facies is exposed along the Murchison Highway (Fig. 3.1). This facies consists of coarse-grained, poorly sorted, breccia intercalated with mafic sandstone and siltstone and basaltic lavas. Single beds are 4-80 m thick, have limited lateral extent (<500 m), sharp lower contacts, massive bodies and normally graded, stratified, siltstone tops (Fig. 3.11). Soft sediment folds and flames into the overlying bed commonly disrupt the stratification.

This facies is characterised by clast-supported aggregates of angular to subangular, blocky to ragged clasts in a chlorite-epidote-rich matrix that contains 5-20% plagioclase crystals and crystal fragments (Figs. 3.11B, D and 3.12). Clasts can include: massive feldspar-phyric dacite/andesite, micropoikilitic feldspar-hornblende-phyric dacite, spherulitic feldspar-phyric dacite, amygdaloidal aphyric basalt, perlitic aphyric basalt and basaltic scoria. Amygdales are filled with sericite-hematite and chlorite (Fig. 3.11D). Lithic clasts have been altered to chlorite, sericite, hematite, epidote, calcite and feldspar. Oval and tube vesicles in the basaltic scoria are coated in a thin film of hematite and/or sericite. Plagioclase crystals are partially replaced by sericite and epidote.

Clasts average less than 10 cm in size but can be up to 1 m in diameter. Commonly clasts are blocky and angular with at least one curviplanar surface. Some large (>10 cm) amygdaloidal aphyric basalt clasts have a single curved surface with fine-grained, perlitic, zoned rims. Vesicular and amygdaloidal clasts have irregular and ragged shapes (Fig. 3.11D). The clasts are typically randomly oriented, however locally jigsaw-fit textures occur (Fig. 3.12).

3.11.2 Mafic volcanic sandstone facies

Mafic volcanic sandstone facies is limited to drill core in the Sterling Valley Volcanics (Fig. 3.11). This facies is interbedded with mafic volcanic siltstone and sparse, polymictic mafic breccia in 20-40 m-thick intervals. Single beds are thin (0.2-2 m) and both normally and reversely graded. The mafic volcanic sandstone facies is characterised by diffuse laminations, on a mm to cm scale (Fig. 3.11E).

This facies is composed of feldspar crystals and crystal fragments (10%, 1-2 mm) and volcanic lithic clasts (90%, 0.2-3 mm) which include: basaltic scoria, aphyric basalt and feldspar-phyric dacite or andesite. Sparse outsized clasts have blocky shapes and curviplanar margins.

3.11.3 Mafic volcanic siltstone facies

Mafic volcanic siltstone is also limited to drill core in the Sterling Valley Volcanics (Fig. 3.11). The mafic volcanic siltstone facies is characterised by diffuse laminations, on a mm scale and is interbedded with mafic volcanic sandstone and polymictic mafic breccia (Fig. 3.11E). Units of mafic volcanic siltstone are up to 5 m thick. This facies is composed of sub-millimetre grains of chlorite, muscovite, magnetite, hematite and feldspar.

3.11.4 Interpretation

The polymictic mafic breccia and mafic volcanic sandstone comprise similar clasts types suggesting that they are genetically related. The spatial association of the polymictic mafic breccia and mafic volcanic sandstone with facies that are texturally and compositionally similar to clasts within the polymictic mafic breccia is consistent with the derivation of clasts from local sources. Dacite, andesite and basalt clasts in the polymictic mafic breccia facies commonly have chilled, curviplanar margins indicating that they were sourced from quench fragmented debris (cf. Pichler, 1965; Yamagishi, 1987). Local zones of jigsaw-fit clasts indicate in situ fragmentation consistent with the disintegration of fractured clasts derived from hyaloclastite. Basalt clasts with curved surfaces and perlitic, zoned rims may be fragments of basaltic pillows. The ragged shapes of scoria clasts in the polymictic mafic breccia facies may be produced by the rapid expansion of vesicles during explosive eruption or during autobrecciation of highly vesicular basaltic lava.

Interbedded polymictic mafic breccia, mafic volcanic sandstone and siltstone suggests that the clast supply was erratic. The internal organisation and bedforms of the polymictic mafic breccia are consistent with deposition by density-modified grain flows or debris flows (cf. Smith, 1986; Lowe, 1982; Einsele, 1991; Allen, 1995 unpub.). Mafic volcanic sandstone and siltstone beds were probably deposited from high-concentration turbidity currents (cf. Lowe, 1982)

The polymictic clast population in these facies suggests that they are not related to a single eruption. However, the angular nature of clasts, presence of delicate scoria clasts, lack of non-volcanic clasts or intercalated unrelated facies in the polymictic volcanic facies association suggest that deposition occurred soon after eruption and that reworking was minimal. This facies association was broadly syn-eruptive.

3.12 Black mudstone facies

Intervals of black mudstone are sparse in the Mount Black and Sterling Valley Volcanics. Black mudstone units are typically less than 1 m thick and are best preserved adjacent to coherent rhyolite to basalt where the mudstone is silicified and massive. Away from the immediate contact it is typically dark grey to black and finely (0.5-2 mm) laminated. It is dominantly composed of polycrystalline quartz, mica and pyrite (~1%).

3.13 Massive basalt and dolerite

Abundant dark green, massive, basalt and dolerite units occur throughout the Mount Black and Sterling Valley Volcanics (Figs. 3.2, 3.3, 3.5B and 3.12). The abundance of these units increases in the Sterling Valley Volcanics and towards the Henty Fault. They are generally several cm to 3 m thick and have mapped extents of less than 100 m. They are irregular, branching bodies which have sharp irregular upper and lower contacts and where bedding is observed in the host facies they are discordant. They have fine-grained margins and haloes of chlorite-pyrite-carbonate-rich alteration extend up to 10 cm into the host facies.

This facies is aphyric to weakly (<3%) plagioclase-phyric. The groundmass consists of interlocking feldspar laths and prismatic chlorite-altered needles. These massive basalts and dolerites are strongly altered to an assemblage of epidote-chlorite-calcite ± hematite ± pyrite. Amygdales are filled with concentric zones of quartz-chlorite, quartz-chlorite-quartz, quartz-chlorite-epidote or quartz-chlorite-calcite. Commonly massive basalt and dolerite units have a moderately well developed spaced cleavage (S_2).

3.13.1 Interpretation

The geometry, sharp irregular contacts and cross-cutting nature of this facies is consistent with the interpretation of basaltic dykes. The absence of peperite associated with the margins of these dykes suggests that they were probably emplaced post-lithification and the S_2 cleavage indicates that they pre-date Devonian deformation. The alteration haloes in the adjacent facies are interpreted as narrow contact metamorphic aureoles.

These basalt and dolerite dykes have previously been recognised as part of the Henty Dyke Swarm (Chapter 2) (Corbett and McNeill, 1986; Crawford et al., 1992).

3.14 Carbonate facies association

Carbonate facies only occur in the Mount Black Volcanics and are limited to drill core from the western side of Mount Black south to Dalmeny prospect. The carbonate facies have been intersected in drill holes: DP5, DP259, DP317, 60R, 65R, 74R, 76R, 78R, 80R and 128R (Figs. 3.1, 3.3 and 3.20). Carbonate units average 2 m in thickness (4 cm - 35 m) and can be traced in drill core for 3 km. Contacts are typically sharp and planar or irregular, although several lower contacts are faults (Fig. 3.20). Carbonate units underlie or occur within units of pumice-lithic clast-rich breccia or monomictic rhyolite breccia (Fig. 3.20). Commonly, strong calcite-quartz-hematite alteration occurs in the adjacent facies and carbonate-altered clasts are present in adjacent pumice-lithic clast-rich breccia units.

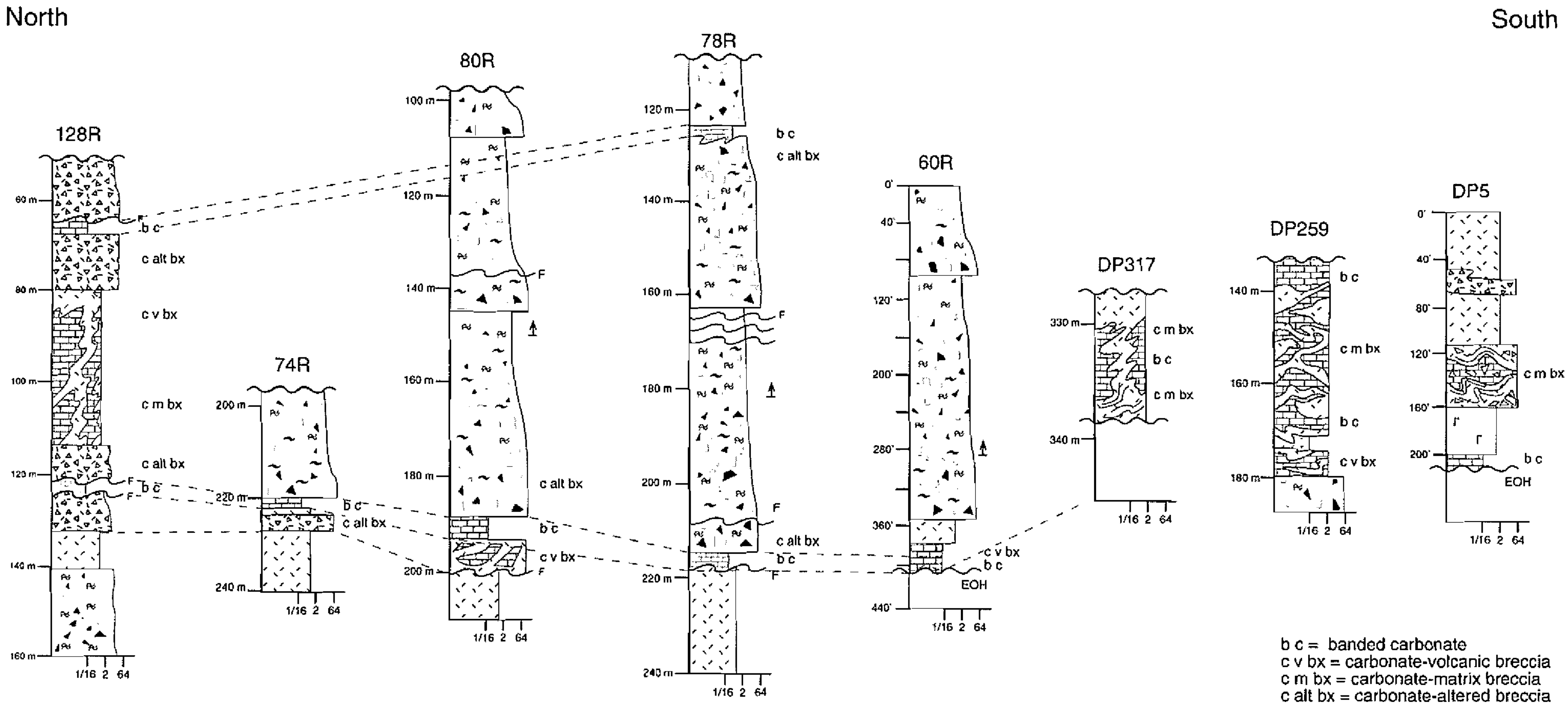


Figure 3.20: The carbonate facies association in the Mount Black Volcanics can be traced south of Rosebery 4 km to Dalmeny. The carbonate facies association is spatially associated with coherent rhyolite, monomictic rhyolite breccia, rhyolite mixed breccia and pumice-lithic clast-rich breccia. See Figure 3.1 for position of drill collars and Figure 3.4 for legend to graphic log symbols.

The carbonates are sparry and white to pink/purple and pale green in handspecimen (Fig. 3.21). In thinsection, they consist of coarse equigranular calcite with minor hematite, quartz and sericite (Fig. 3.21D).

Textural types of carbonate in the Mount Black Volcanics include: banded carbonate, carbonate-volcanic breccia and carbonate-matrix breccia.

3.14.1 Banded carbonate facies

The banded carbonate facies occurs in units up to 8 m thick and commonly grades into massive carbonate, carbonate-volcanic breccia or carbonate-matrix breccia. This facies has a strong bedding-parallel foliation defined by green sericite-rich bands or hematite-rich spaced stylolites in calcite-quartz-sericite (Figs. 3.21C, D, E, F G and H). The bands are 2 mm to 3 cm thick. This foliation is typically planar and discontinuous, although two intervals of folded banded carbonate have been intersected (78R 214.5 m, Figs. 3.21E and F, and DP259 150.9m). The banding in these intervals is crenulated by the tectonic foliation (S_2).

3.14.2 Carbonate-volcanic breccia facies

Carbonate-volcanic breccia consists of white and purple carbonate clasts (0.5-6 cm) and dark grey feldspar-phyric volcanic clasts (2-5 cm) in a purple matrix. One sample (65R 195') also contains feldspar-phyric fiamme and large (up to 10 cm) uncompacted pumice clasts (Fig. 3.21A). Clast shapes vary from blocky to fluidal and ragged. Typically the carbonate and volcanic clasts have diffuse margins and the proportions of clast types vary among and within intervals. Intervals also vary from clast- to matrix-supported and are poorly sorted. Local domains of jigsaw-fit carbonate clasts are preserved. Hematite-rich stylolites within and at the margins of the carbonate clasts have random orientations.

In thinsection, relic euhedral calcite-altered feldspar crystals are preserved in the carbonate clasts and the purple colour reflects fine disseminated hematite.

3.14.3 Carbonate-matrix breccia facies

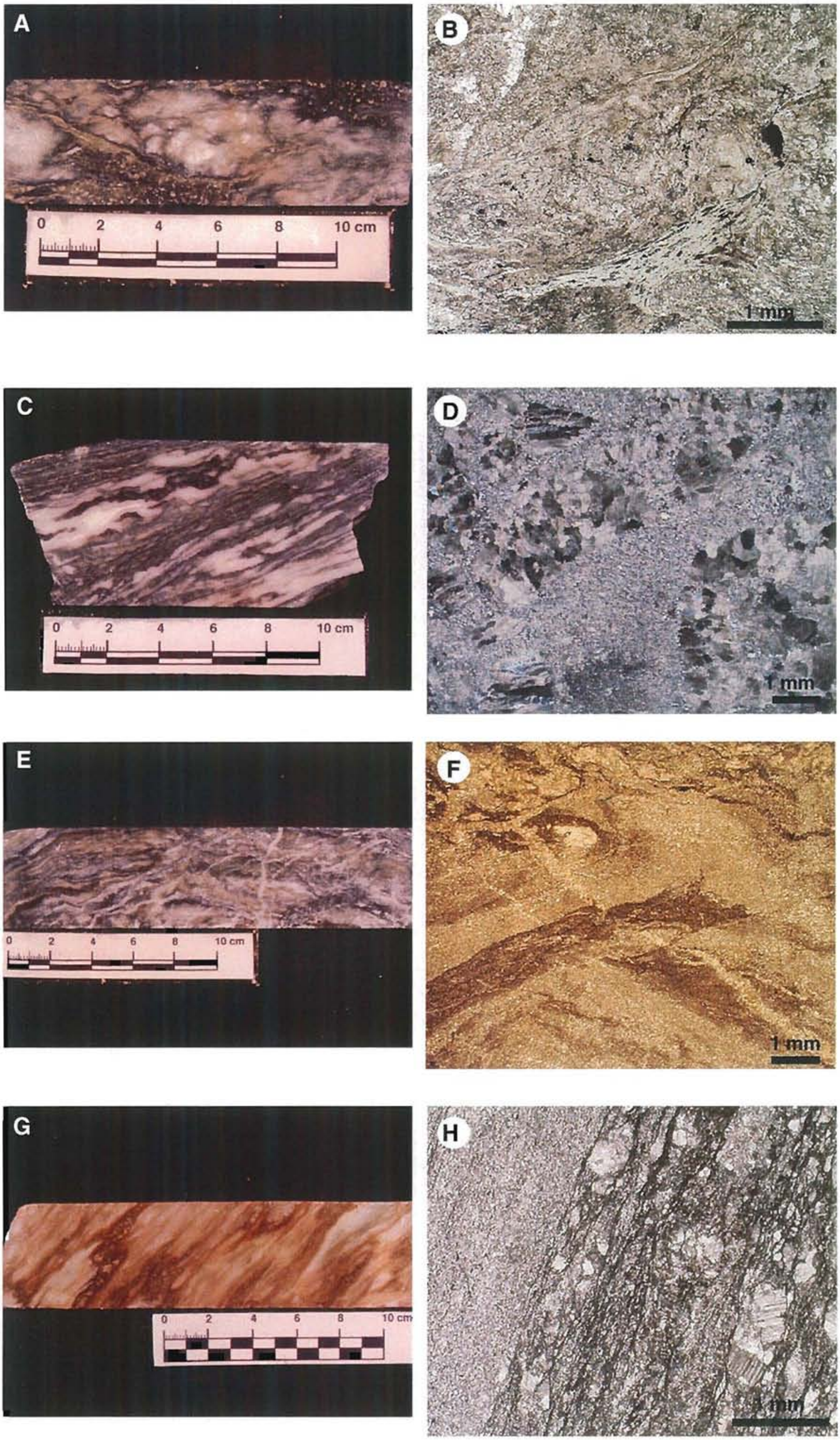
This facies was recognised in drill hole 128R at ~80 m depth (Fig. 3.22). The 30 m-thick unit consists of feldspar-phyric volcanic clasts (1-3 cm) within a white, massive carbonate matrix. The fabric varies from clast-supported with wispy stringers of carbonate to matrix-supported where blocky feldspar-phyric volcanic clasts are dispersed in white carbonate. Feldspar-phyric volcanic clast shapes vary from blocky to fluidal.

Carbonate-matrix breccia grades down-hole into jigsaw-fit rhyolite breccia with a calcite-quartz-hematite-altered matrix. Up-hole carbonate-matrix breccia, containing jigsaw-fit feldspar-phyric volcanic clasts in irregular stringers of carbonate, grades into carbonate-volcanic breccia, with dispersed blocky carbonate clasts in a feldspar-phyric domain, and then into jigsaw-fit carbonate clasts (Fig. 3.22).

3.14.4 Origin of the carbonate

In carbonate-volcanic breccia facies, diverse crystal contents, textural variations, gradational contacts with calcite-quartz-hematite-altered pumice-lithic clast-rich breccia (drill holes 78R and 80R; Fig. 3.20) and the preservation of pumice clasts (drill hole 65R) suggest that the carbonate-volcanic breccia facies is a carbonate-altered polymictic volcanic breccia, such as pumice-lithic clast-rich breccia.

Figure 3.21: Handspecimen and thinsection photographs of carbonate facies in the Mount Black Volcanics. A. Patchy and diffuse carbonate in carbonate-volcanic breccia (65R 197'). B. Photomicrograph (ppl) of sericite-hematite fiamme and carbonate-altered tube pumice clasts in carbonate-volcanic breccia (65R 197'). C. Banded carbonate (74R 220 m). D. Photomicrograph (xn) of bands of fine and coarse equigranular calcite with minor hematite, quartz and sericite in banded carbonate (128R 69 m). E. Banded and folded carbonate (78R 214 m). F. Photomicrograph (ppl) of E. Folded and brecciated bands of coarse- and fine-grained calcite, hematite, sericite and quartz. G. Banded carbonate (80R 191 m) with feldspar-phyric, sericite-rich lenses attenuated in the regional cleavage. H. Photomicrograph (ppl) of banded carbonate (80R 189.5 m). Subhedral domains of coarse calcite within a finer-grained matrix of calcite, quartz and hematite, may be pseudomorphs of primary feldspar crystals. A strong sericite-hematite stylolitic foliation wraps around these coarser-grained domains of calcite.


A
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B
1 mm
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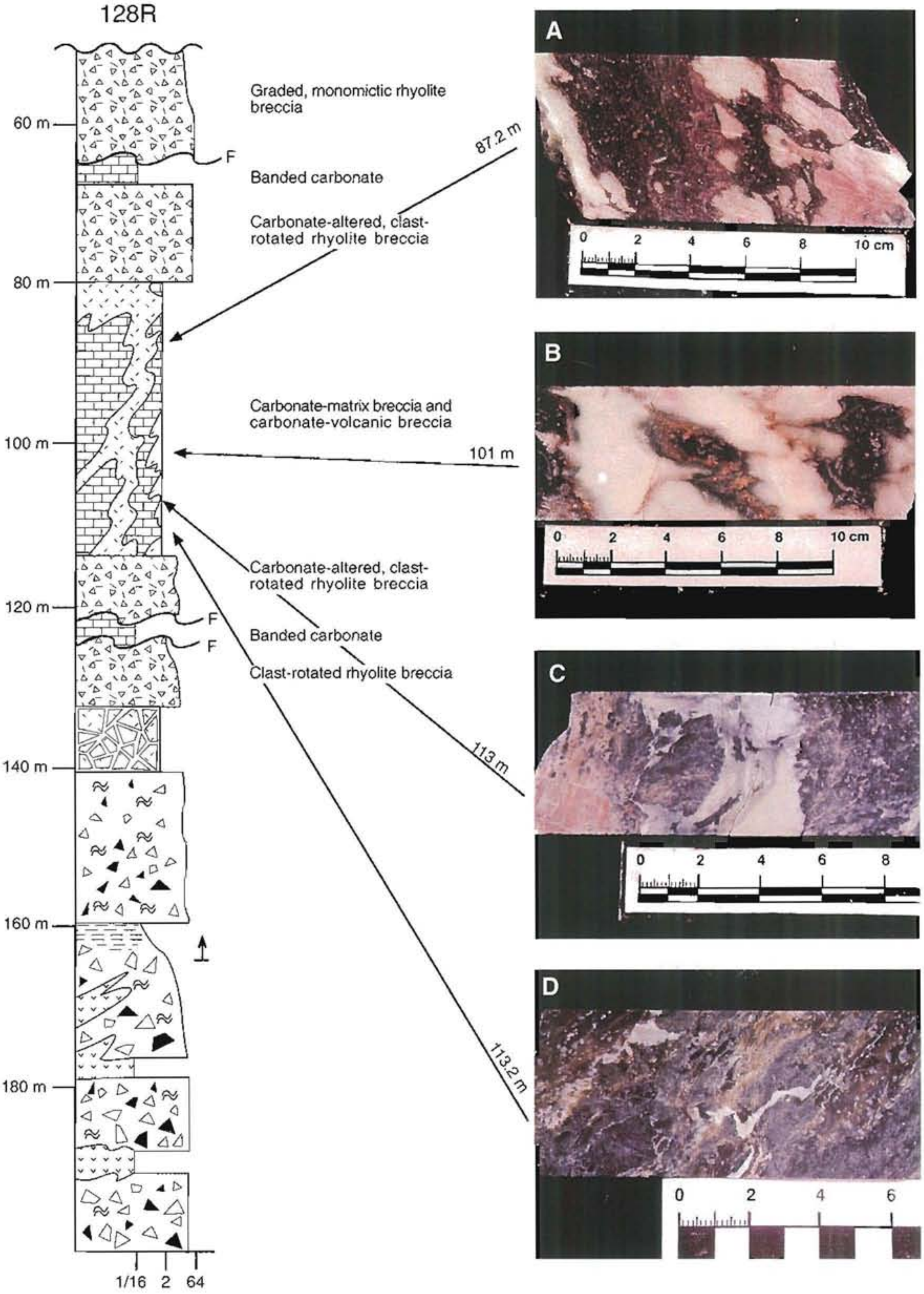

Figure 3.22: Detailed graphic log through a carbonate interval east of Rosebery (drill hole 128R). Carbonate-altered monomictic rhyolite breccia grades up-hole into carbonate-matrix breccia and carbonate-volcanic breccia. See Figure 3.4 for legend to graphic log. A. Carbonate-volcanic breccia (128R 87.2 m). Pink and white carbonate clasts are surrounded by sericite-carbonate-altered, feldspar-phyric, rhyolite. B. Carbonate-matrix breccia (128R 101 m). Irregular clasts of feldspar-phyric rhyolite are enclosed in white carbonate. Dark sericite-hematite and hematite stylolites occur in the carbonate. C. Carbonate-matrix breccia (128R 113 m). Clast-rotated and jigsaw-fit feldspar-phyric rhyolite clasts are hosted in white carbonate. D. Carbonate-matrix breccia (128R 113.2 m). Thin stringers or seams of white carbonate occur within feldspar-phyric rhyolite.

In drill hole 128R, similar feldspar crystal contents and a gradational contact between carbonate-matrix breccia and jigsaw-fit rhyolite breccia facies suggest that they are genetically related. The carbonate-matrix breccia is interpreted as carbonate-altered breccia. Wispy stringers of carbonate and feldspar-phyric volcanic clast shapes may be consistent with the interpretation that the carbonate-matrix breccia is carbonate-altered peperite (rhyolite mixed breccia) at the upper contact of the underlying hyaloclastite (jigsaw-fit rhyolite breccia).

Folded banding and crenulated stylolites in the banded carbonate facies suggest that carbonate formed prior to deformation (S_2) and prior to or synchronous with compaction and the development of the stylolitic foliation (S_1) (Chapter 6).

Carbonate facies in the Mount Black Volcanics have previously been interpreted as limestones (Lees, 1987) and, based on carbon and oxygen isotope data, as Cambrian hydrothermal carbonates (Warmeant, 1990). The carbon-oxygen isotope results plot within the field for Henty carbonates (Fig. 3.23). Henty carbonates were interpreted to represent Cambrian hydrothermal isotope values and to be related to massive sulfide mineralisation at Henty (Yeats, 1989; Khin Zaw, 1991; Halley and Roberts, 1997). Recently, the Henty carbonates were found to contain shallow marine fossils and were traced south for several kilometres to fossiliferous limestone (Callaghan, in press). Typically fossiliferous limestones in the Mount Read Volcanics, such as those at Comstock, have higher $\partial^{18}O$ and $\partial^{13}C$ values (White, 1996). The conflicting isotope data may reflect carbonates formed by either precipitation due to mixing of magmatic CO_2-rich fluid with seawater at and below the seafloor or Cambrian hydrothermal alteration of fossiliferous limestones (Callaghan, in press).

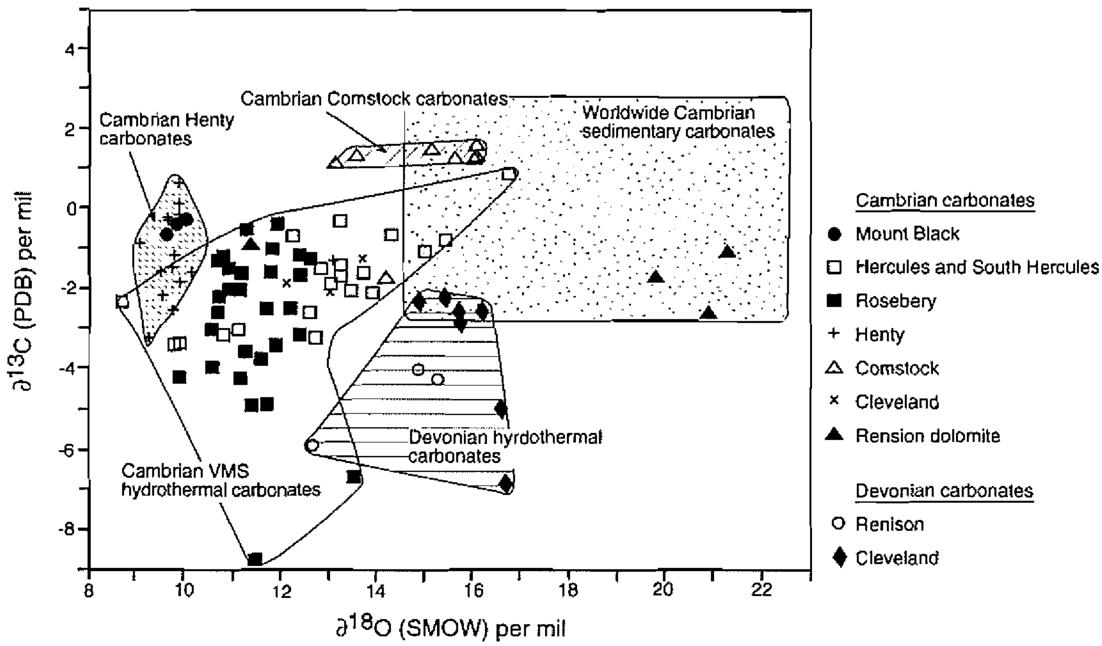

Figure 3.23: Plot of $\partial^{18}O$ versus $\partial^{13}C$ for carbonates in western Tasmania. Plotted are fields for Cambrian and Devonian hydrothermal carbonates in western Tasmania. Carbon-oxygen isotope values for Comstock from MacDonald (1991), Henty from Yeats (1989), Rosebery and Hercules from Dixon (1980) and Khin Zaw (1991), Cleveland from Collins (1981), Renison from Patterson et al. (1981) and Mount Black from Warmeant (1990). Also shown is the field for worldwide Cambrian marine carbonates analysed by Veizer and Hoefs (1976).

Although the carbonate-breccia intervals in the Mount Black Volcanics are both isotopically and texturally similar to some of the carbonate units at the Henty mine (cf. Halley and Roberts, 1997; Callaghan, 1998), handspecimen, thinsection and dissolution studies failed to find any evidence for fossils. In addition, the immobile element signature (Appendix D) of the carbonates indicates a rhyolitic component within this facies. The recrystallised nature of the calcite, the lack of fossils and the presence of carbonate alteration in the adjacent units suggest an origin of hydrothermal carbonate alteration.

3.15 Provenance and the environment of deposition

3.15.1 Environment of deposition

Evidence for the depositional environment of the Mount Black and Sterling Valley Volcanics is limited. A subaqueous, below-wave-base depositional environment is interpreted based on:

(1) Sedimentary structures (cross-laminated, graded bedding, planar laminations) in the interbedded pumice-rich sandstone and shard-rich siltstone facies suggest that deposition was from turbidity currents.

(2) Finely laminated shard-rich siltstone is associated with cross-laminated, graded and interbedded pumice-rich sandstone and shard-rich siltstone turbidites and the tops of thick mass-flow-emplaced pumice breccia beds. This suggests that the laminated siltstone was deposited either from turbidity currents or by water-settled fall. A subaqueous environment of deposition for the laminated shard-rich siltstone is consistent with the interpretation of the outsized fiamme in the shard-rich siltstone as water-logged pumice clasts, which settled from suspension at the waning stages of eruption.

(3) Clast-supported, moderately sorted beds of pumice breccia and pumice-lithic clast-rich breccia have massive interiors and normally graded or diffusely stratified tops consistent with deposition by water-supported gravity flows. These deposits are texturally similar to volcaniclastic breccias described from other subaqueous silicic successions (Fiske and Matsuda, 1964; Kokelaar et al., 1985; Soriano and Marti, 1999; Cas and Wright, 1991; McPhie and Allen, 1992a).

(4) Massive thick beds of crystal-rich sandstone are typical of deposits from high-concentration density currents, possibly sandy debris flows.

(5) The bedforms in the polymictic mafic facies association suggest deposition from density-modified grain flows, high-concentration debris flows or turbidity currents.

(6) Rare laminated black mudstone interbedded with pumice-rich sandstone and shard-rich siltstone facies, and the polymictic volcanic facies association contains biogenic pyrite and implies quiet, deep marine conditions.

(7) The abundance and large volume of hyaloclastite (monomictic rhyolite breccia, monomictic dacite breccia, monomictic feldspar-hornblende-phyric dacite breccia and monomictic mafic breccia) indicate emplacement in a subaqueous setting or intrusion into wet unconsolidated sediment (cf. Pichler, 1965).

(8) The regional context of the Mount Black and Sterling Valley Volcanics in the Central Volcanic Complex constrains the broad environment of deposition to submarine based on the presence of hyaloclastite, turbidites and VHMS mineralisation (Allen and Cas, 1990 unpub.). Although the occurrence of VHMS mineralisation suggests that deposition occurred in a submarine environment, it does not constrain the water depth. Massive sulfide mineralisation associated with active hydrothermal systems has been found at water depths between 80 and 3700 m (Herzig and Hannington, 1995; Marani et al., 1997; Hannington et al., 1999a; Hannington et al., 1999b unpub.; Hannington and Herzig, 2000 unpub.).

Several volcaniclastic facies in the Mount Black and Sterling Valley Volcanics imply deposition from turbidity currents, debris flows and suspension sedimentation. These are the three dominant processes by which sediment is distributed in deep marine settings. The lack of tractional current structures suggests that the depositional environment was largely below storm wave-base, however no other constraints on water depth are available. The depth of storm wave-base is extremely variable, in modern oceans it ranges from 10 to 200 m (Reading, 1986). It is also possible that there was significant variation in water depth within the study area.

3.15.2 Provenance of volcanic and sedimentary facies

Volcanic and sedimentary facies in the Mount Black and Sterling Valley Volcanics vary from proximal to distal, syn-eruptive to post-eruptive facies and reflect a variety of sources. Discussion of the source or provenance of the volcanic and sedimentary facies is subdivided into six types of facies associations with different provenance and timing: (1) proximal felsic facies associations of the Mount Black Volcanics dominated by rhyolitic and dacitic lavas and sills (rhyolite facies association, dacite facies association and feldspar-hornblende-phyric dacite facies association); (2) proximal to medial mafic facies associations of the Sterling Valley Volcanics, including basaltic and andesitic lavas and sills (mafic facies association) and dacitic lavas and sills (dacite facies association); (3) syn-eruptive regionally extensive pumice-rich facies associations; (4) syn-eruptive pumice-lithic clast-rich facies association; (5) post-eruptive crystal-rich facies association; and (6) black mudstone. The Cambrian hydrothermal sub-seafloor replacement origin of the carbonate facies association is discussed in section 3.14.4.

In the Mount Black Volcanics, lavas are interleaved with turbidites and other volcanic mass-flow units, suggesting that effusive eruptions occurred in the submarine environment. The high proportion of lavas to volcaniclastic or sedimentary facies in the Mount Black area also suggests proximity to an effusive source.

The mafic Sterling Valley Volcanics include lavas and sills hosted in mafic volcaniclastic facies interpreted to be submarine. Abundant coherent (aphyric and feldspar-phyric andesite and basalt) and in situ brecciated facies (monomictic mafic breccia), and the lack of significant reworking suggest that deposition occurred relatively near vent. However, the thick (>100 m) succession of interbedded resedimented syn-eruptive volcaniclastic facies (polymictic mafic breccia, mafic volcanic sandstone and siltstone) and polymictic clast population may reflect deposition on the flanks of the volcanic complex (medial facies). Quench fragmentation of the lavas and sills and the occurrence of pillow fragments indicate that either the vent was submarine or that lava flowed into the sea from an emergent vent.

The pumice-rich facies association is spatially associated with compositionally similar rhyolite lavas and sills (Chapter 4). The lavas and sills have lateral extents of less than 2 km and are unlikely to have spread far from their conduits. Thick (>100 m) regionally extensive pumice breccia, the lack of other facies intercalated with the association, and the spatial association with the proximal facies of lavas and sills suggest that the pumice-rich facies association is close to the source, probably within several kilometres of the vent. The inferred proximity to source, below-wave-base environment of deposition, and lack of reworking suggest that the pumice-rich facies association was either erupted from a submarine vent or from an adjacent subaerial vent and rapidly deposited in a submarine setting. The lack of reworking at the top of the pumice-rich facies association, implying that deposition occurred below storm wave-base, and the thickness of the facies association (>500 m) suggest that deposition occurred at water depths in excess of 700 m. Pyroclasts in the pumice breccia and sandstone facies were derived from large volume, silicic explosive eruption/s. The concept of deep water felsic explosive eruptions has been strongly debated (McBirney, 1963; Cas and Wright, 1991). Explosive fragmentation can occur only if the hydrostatic pressure exerted by the water column allows rapid expansion of volatiles in the magma. In sea water, this occurs theoretically at depths of less than 3 km (less than 500 m for mafic magmas and 1000 m for felsic magmas) (McBirney, 1963; Bischoff and Rosenbauer, 1984; Kokelaar, 1986). However, recent observations from the Myojin Knoll volcano in the Izu-Bonin arc suggest that felsic pyroclastic pumice can be erupted at water depths of 900 m and that large explosive eruptions can occur at water depths greater than 600 m (Fiske et al., in press).

Pumice-lithic clast-rich facies association comprises locally available clasts, and is probably a proximal facies association derived from the resedimentation of clasts on the seafloor (sections 3.8.3 and 3.10.4).

The only distal and post-eruptive facies in the Mount Black and Sterling Valley Volcanics is the crystal-rich sandstone facies, which contains a wide variety of volcanic and non-volcanic clasts and crystal fragments indicating a mixed provenance (section 3.10.1). The inclusion of clasts derived from Precambrian and Early Cambrian successions suggests that this facies was sourced from west of Rosebery where Precambrian basement and Crimson Creek Formation occur (Chapter 2).

Black mudstone is finely laminated and typically contains approximately 1% biogenic pyrite, which is consistent with the interpretation that it formed by deep marine sedimentation (cf. O'Brien, 1996).

3.16 Facies architecture

The marked compositional differences between facies of the Mount Black and Sterling Valley Volcanics allow the discussion of two volcanic successions or stages of volcanic activity, the Mount Black Volcanics (Fig. 3.24) and the Sterling Valley Volcanics (Fig. 3.25). The relationship between these two volcanic successions is discussed in Chapter 4.

3.16.1 Mount Black Volcanics

The Mount Black Volcanics record two distinctive styles of eruption: effusive and explosive eruptions. The products of these two eruption styles are intercalated in a below-wave-base submarine environment

(Fig. 3.24). Coherent and autoclastic (autobreccia and hyaloclastite) facies, and resedimented syn-eruptive autoclastic facies (graded and stratified monomictic breccia and pumice-lithic clast-rich breccia) record effusive volcanism. Explosive eruptions are recorded by the syn-eruptive pumice-rich facies association (pumice breccia, pumice-rich sandstone and shard-rich siltstone). Post-eruptive resedimentation is evident only in the crystal-rich sandstone.

The facies for which significant lateral transport can be reasonably inferred (pumice breccia, pumice-rich sandstone, shard-rich siltstone, graded and/or stratified rhyolite or dacite breccia, pumice-lithic clast-rich breccia and sandstone, and crystal-rich sandstone facies) mark seafloor positions in the volcanic succession.

Effusive volcanism

The Mount Black Volcanics are dominated by the intrabasinal, proximal lithofacies generated by effusive eruptions and shallow intrusions: lavas, domes, cryptodomes and syn-volcanic sills. These lavas and intrusions are composed of variable amounts of coherent, in situ and resedimented autoclastic facies. The lavas and intrusions have similar mineralogy, geochemistry (Chapter 4) and primary volcanic textures and are best distinguished on the basis of their contact relationships and the distribution of coherent facies, autobreccia, hyaloclastite, peperite and resedimented units. As contacts are rarely exposed in the field and are often ambiguous in drill core, the intrusive or extrusive nature of many coherent rhyolites and dacites remains unknown.

The rhyolitic and dacitic lavas and intrusions are interpreted to represent the proximal facies and intrusive roots of a large dacitic to rhyolitic volcanic complex. The paucity of intervening volcano-sedimentary units implies that the lavas were either erupted rapidly from adjacent vents or fissures or that they constructed significant topography that strongly influenced post-eruptive sedimentation patterns and inhibited all other sedimentation. Felsic lava- and intrusion-dominated complexes are common in other ancient submarine volcanic successions (eg. Kano et al., 1991; Yamagishi and Matsuda, 1991; Cas et al., 1990; Cas and Bull; 1993; Allen, 1992a; McPhie et al., 1993; Allen et al., 1996; Paulick and McPhie, 1999; Doyle and McPhie, 2000).

Lavas and domes: The thickness and extent of single lavas in the Mount Black Volcanics varies. Some form thin, laterally extensive units and others are thick, high-aspect-ratio units similar to lava domes (cf. Rose, 1972; Kano et al., 1991). Rhyolitic units in the Mount Black Volcanics average 1-100 m in thickness and less than 500 m in extent. This is similar to rhyolitic lava domes in other modern and ancient submarine volcanic successions (cf. Horikoshi, 1969; Kokelaar et al., 1985; Kano et al., 1991; Yamagishi and Matsuda, 1991; Yamagishi and Goto, 1992; Waters and Binns, 1998 unpub.). The dacitic units are thick and laterally extensive units, up to 300 m by 2 km, typical of felsic lavas (cf. De Rosen-Spence et al., 1980; Cas and Bull, 1993; Hanson and Wilson, 1993).

Although the domes are laterally less extensive, felsic lavas and domes in the Mount Black Volcanics display a similar range in textures and morphology. The internal structure is commonly concentric, consisting of a massive core, flow-banded rind, in situ brecciated margin and an envelope or carapace of breccia (Fig. 3.24). The core of the lavas is microcrystalline, either densely microspherulitic or micropoikolitic. Commonly surrounding the core facies is a massive perlitic or

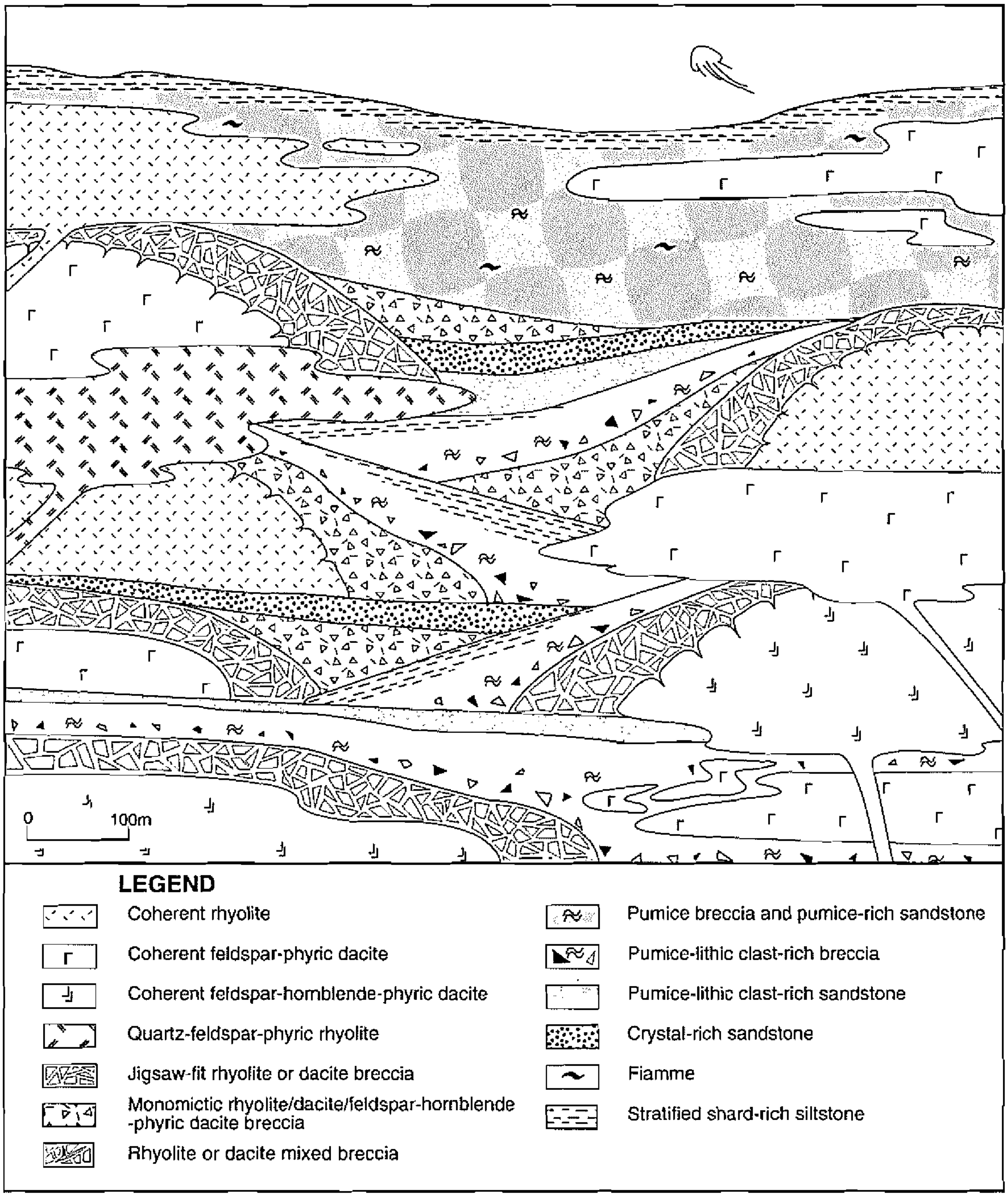

Figure 3.24: Schematic diagram depicting the volcanic architecture of the Mount Black Volcanics, the proximal facies and intrusive roots of a large felsic submarine volcanic complex.

flow-banded rind. Flow-bands are approximately parallel to the adjacent margin and were originally defined by crystalline versus glassy layers. In some cases, the rind and associated hyaloclastite are highly vesicular or pumiceous (Chapter 5). The massive and flow-banded coherent facies are overlain by or enclosed in a carapace of monomictic rhyolite or dacite breccia. Jigsaw-fit and clast-rotated monomictic breccia are interpreted to be hyaloclastite produced by quench fragmentation at the margins of the lava or dome. Blocky, flow-banded breccia is interpreted as autobreccia formed as cooler and more viscous margins of the flow were deformed and fragmented in response to the continued flow of the more ductile interior. Monomictic rhyolite or dacite breccia facies also occurs in lenses (1-6 m thick) within the coherent facies of the lavas and domes. Where exposed, the basal contacts of the lavas and domes are typically peperitic. This suggest that the lava flowed over and locally burrowed into wet, unconsolidated sediment.

The shape, dimensions and internal textural variations in the rhyolitic and dacitic lavas and domes in the Mount Black Volcanics are similar to the morphology of felsic lavas and domes in other submarine and also subaerial volcanic successions (cf. Eichelberger et al., 1986; Manley and Fink, 1987; Kurokawa, 1991; Yamagishi and Matsuda, 1991; Stevenson et al., 1994).

Syn-volcanic intrusions: Rhyolitic and dacitic syn-volcanic intrusions are abundant in the Mount Black Volcanics. The syn-volcanic intrusions include feldspar-phyric and quartz-feldspar-phyric mineralogies. These intrusions are scattered throughout the succession, dissecting pre-existing facies (Fig. 3.24). They typically have peperitic contacts which suggests that they were emplaced into water-saturated unconsolidated sediment at relatively shallow levels (ten's of metres) below the seafloor (Hanson and Wilson, 1993). Sediments within a few hundred metres below the seafloor are generally wet and poorly consolidated and become increasingly dense, compacted, and lithified with depth (Einsele, 1986). The intrusion of magma is favoured over extrusion where the density of the magma exceeds that of the host succession or where the hydrostatic pressure of the magma is low (McBirney, 1963). This is common in subaqueous successions where thick intervals of unconsolidated sediment have accumulated. Intrusion of magma also occurs in association with the extrusion of lavas close to subaqueous vents (Kokelaar et al., 1985). In the Mount Black Volcanics, the low density of pumice-rich volcaniclastic facies probably promoted intrusion.

The syn-volcanic intrusions in the Mount Black Volcanics have three morphologies: extensive sheet-like sills, dykes and lenticular cryptodomes.

Syn-volcanic sills in the Mount Black Volcanics are tabular, laterally extensive with broadly concordant and locally discordant contacts. They are typically less than 100 m thick and can extend for up to 2 km along strike. Some are discontinuous pod-like bodies, only several metres thick that may represent lobes of lava that burrowed or intruded into unconsolidated sediment. Rhyolitic and dacitic sills commonly have very irregular, bulbous and peperitic margins along both the upper and lower contacts. They generally have coherent, microspherulitic or micropoikolitic or perlitic cores, which suggests that the sills were originally crystalline or glassy. The margins of the sills grade into jigsaw-fit rhyolite or dacite breccia facies (in situ hyaloclastite) and rhyolite or dacite mixed breccia facies (peperite) as a result of in situ quench fragmentation by seawater and wet unconsolidated sediment. The rotation of some clasts in the clast-rotated rhyolite or dacite breccia may due to continued injection of magma (cf. Kokelaar et al., 1985).

Syn-volcanic dykes (quartz-feldspar-phyric rhyolite facies association) in the Mount Black Volcanics are thick (<200 m) and laterally extensive (<1500 m). They are mainly dominated by coherent facies with irregular peperitic margins.

Cryptodomes are near-surface intrusions that result in the up-doming of the overlying sediments or lavas and generate seafloor topography (Minakami et al., 1951; Allen, 1992a). In the Mount Black Volcanics, cryptodomes form lensoidal bodies up to 300 m thick and several hundred metres lateral extent. Contacts are discordant and marked by peperite and in situ hyaloclastite. Internally, the cryptodomes are composed of coherent, originally glassy, perlitic, feldspar-phyric rhyolite or dacite. The margins may contain flow-banding parallel to the dome surface. The internal textural variations in these cryptodomes are similar to those of submarine-emplaced rhyolitic lava domes (cf. Kano et al., 1991; Yamagishi and Matsuda, 1991).

Coeval explosive volcanism

Intrabasinal effusive felsic volcanism was coeval with the deposition of pyroclastic debris. In the Mount Black Volcanics, the syn-eruptive pumice breccia, pumice-rich sandstone and shard-rich siltstone facies record explosive volcanism.

The syn-eruptive pumice-rich facies are monomictic, large-volume deposits of juvenile pyroclasts produced by explosive eruption/s. Pumice breccia and pumice-rich sandstone facies were deposited from water-supported gravity flows, possibly high-concentration turbidity currents, debris flows and grain flows. Interbedded pumice-rich sandstone and shard-rich siltstone may have been deposited by turbidites sourced directly from eruption. Alternatively ash suspended in the water column settled from suspension to produce finely-laminated shard-rich siltstone.

The pumice-rich facies association infilled the seafloor topography created by pre-existing lavas, domes and syn-volcanic sills (Fig. 3.24). Pumice breccia and pumice-rich sandstone are the only laterally extensive marker horizons in the Mount Black Volcanics.

Syn-eruptive resedimentation

Resedimented syn-eruptive facies in the Mount Black Volcanics are associated with the products of both effusive and explosive volcanism. The resedimented syn-eruptive facies include: graded and stratified rhyolite and dacite breccia, cross-laminated and interbedded pumice-rich sandstone and shard-rich siltstone, and pumice-lithic clast-rich breccia and sandstone. Resedimentation is interpreted to be by water-supported density flows, probably grain flows, debris flows and turbidity currents. An important characteristic of volcaniclastic density currents is that they can transport coarse clasts (gravel up to 77 cm in diameter) up to 100 km and fine ash up to several 1000 km from source (Einsele, 1991; Ollier et al., 1998).

Graded and stratified rhyolite and dacite breccia comprises juvenile, angular, poorly sorted lava clasts that were sourced from unconsolidated autoclastic deposits. Some units are spatially associated with intervals of mineralogically identical, in situ hyaloclastite and coherent rhyolite or dacite (Fig. 3.24), suggesting a local source. These units are lensoidal, becoming thinner and finer grained away from the source. This facies is typically intercalated with pumice-lithic clast-rich breccia and sandstone.

Remobilisation of unconsolidated hyaloclastite and autobreccia into the surrounding environment may be due to slumping and sliding in response to local uplift, syn-depositional faulting, volcano-tectonic earthquakes, continued extrusion and intrusion of magma or dome-related steam explosions. The endogenous growth of lavas and domes may have resulted in gravitational collapse of the breccia carapace. Resedimentation involved grain flows or water-supported debris flows.

Interbedded pumice-rich sandstone and shard-rich siltstone are spatially and genetically associated with syn-eruptive pumice breccia facies and could be deposited directly from eruption. However, some intervals have sedimentary structures that imply prolonged accumulation by mechanisms including:

tractional sedimentation and high- and low-density turbidity currents. Thus, they may represent local resedimentation of pumice breccia and pumice-rich sandstone facies on the seafloor.

Pumice-lithic clast-rich breccia and sandstone facies are polymictic facies derived largely from the resedimentation of unconsolidated hyaloclastite, autobreccia and/or pyroclasts. Remobilisation of debris may have been initiated by local effusive or intrusive events, syn-depositional faulting, or by small dome-related explosive eruptions. The pumice clasts in these facies could be derived from pre-existing unconsolidated pumice breccia or the pumiceous margins of lava domes and cryptodomes (cf. Fink and Manley, 1987; Cas et al., 1990). In the Mount Black Volcanics, there are well documented examples (Chapter 5) of pumiceous autobreccia and hyaloclastite. The spatial association of some intervals of pumice-lithic clast-rich breccia with clast-rotated and in situ pumiceous hyaloclastite and pumiceous rhyolite suggests that pumice clasts were dome-derived. Small dome-related explosive eruptions could also have produced pumice clasts (cf. Swanson et al., 1987; Fiske et al., 1998). However, most intervals of pumice-lithic clast-rich breccia can not be directly related to a pumiceous lava dome or cryptodome.

Resedimentation of pumice-lithic clast-rich breccia and sandstone was by gravity flows, probably debris flows, grain flows or high-concentration sandy turbidity currents.

Post-eruptive resedimentation

Crystal-rich sandstone facies has a mixed extrabasinal provenance which includes Precambrian and Early Cambrian basement rocks, the Mount Read Volcanics and a distal unconsolidated deposit or eruption of quartz-feldspar-phyric magma. Massive, thick beds of crystal-rich sandstone indicate that post-eruptive resedimentation was from high-concentration density currents, either turbidity currents or sandy debris flows. The crystal-rich sandstone was deposited in topographic lows.

3.16.2 Sterling Valley Volcanics

The Sterling Valley Volcanics are dominated by primary and resedimented syn-eruptive units that are associated with effusive eruptions from a large mafic volcanic centre (Fig. 3.25). The primary units include lavas and sills which comprise coherent (feldspar-phyric dacite, andesite and basalt, aphyric andesite and basalt) and autoclastic facies (monomictic mafic breccia and mixed mafic breccia). Syn-eruptive resedimentation is indicated in graded units of monomictic mafic breccia and for the polymictic volcanic facies association. The base of the Sterling Valley Volcanic centre has been removed by displacement along the Henty Fault.

Effusive volcanism

Lavas in the Sterling Valley Volcanics are dacitic to basaltic in composition. The lavas are composed of massive, coherent, fine-grained, feldspar-phyric or aphyric dacite to basalt and lesser proportions of hyaloclastite and peperite (Fig. 3.25).

The dacitic lavas are texturally, mineralogically and geochemically identical to those described in the Mount Black Volcanics. They are 5-150 m thick and have lateral extents of approximately 2 km. They have cores of spherulitic or micropoikolitic feldspar-phyric dacite, finer-grained perlitic rinds and a carapace of hyaloclastite and/or peperite.

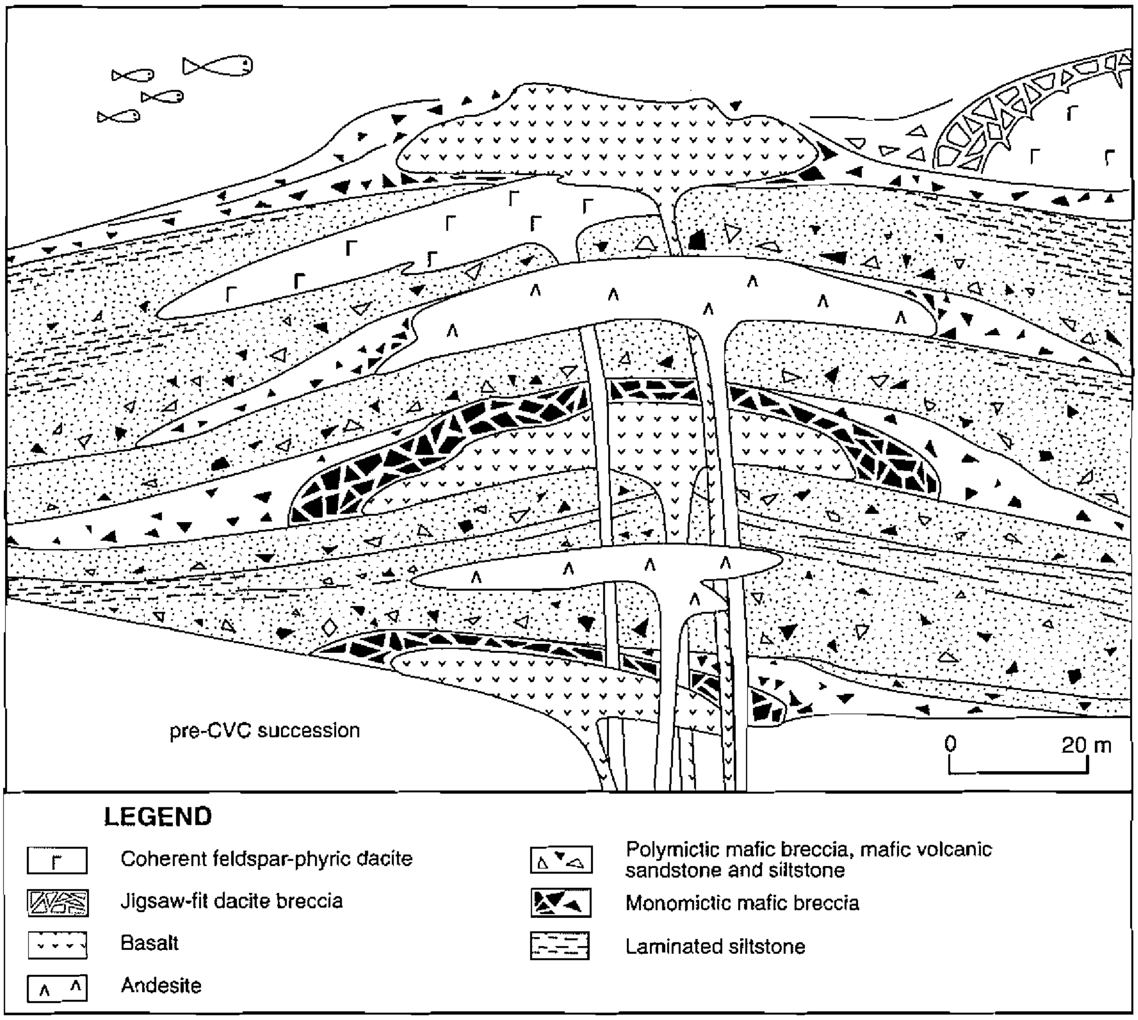

Figure 3.25: Schematic diagram depicting the volcanic architecture of the Sterling Valley Volcanics, proximal facies of a large mafic submarine volcanic centre.

Andesitic and basaltic lavas are typically thin (<100 m thick) and internally massive, with fine-grained crystalline cores, perlitic margins and carapaces of hyaloclastite. The coherent andesite and basalt facies are surrounded or overlain by intervals of in situ hyaloclastite (jigsaw-fit mafic breccia) and redeposited hyaloclastite (normally graded monomictic mafic breccia) (Fig. 3.25). Andesitic and basaltic lavas are conformably overlain by dacitic to basaltic lava or interbedded polymictic mafic breccia, mafic volcanic sandstone and siltstone (Fig. 3.25).

Syn-volcanic intrusions are massive, typically thin (<10 m thick), feldspar-phyric dacitic to basaltic sills and aphyric andesitic to basaltic sills. The sills typically have bedding-parallel margins, although they are locally irregular and commonly marked by peperite (dacite mixed breccia or mafic mixed breccia). This suggests that they intruded unconsolidated, possibly wet, sediments.

Syn-eruptive resedimentation

In the Sterling Valley Volcanics, syn-eruptive resedimentation is indicated for four facies: monomictic mafic breccia, polymictic mafic breccia, mafic volcanic sandstone and siltstone facies.

Sparse normally graded beds of *monomictic mafic breccia facies*, are commonly laterally associated with or directly overlie mineralogically identical, in situ hyaloclastite (monomictic mafic breccia) or coherent andesite or basalt (Fig. 3.25). This suggests that unconsolidated hyaloclastite was redeposited, possibly in response to slope failure, continued effusion of lava, local uplift or movement along syn-volcanic faults. Redeposition was probably by gravity-driven, water-supported mass flows.

Polymictic volcanic facies association comprises broadly syn-eruptive polymictic mafic breccia, mafic volcanic sandstone and siltstone. These facies contain clasts of dacite, andesite, basalt and basaltic scoria. Some clasts shapes and mineralogies are consistent with their derivation from local sources of unconsolidated dacitic hyaloclastite and autobreccia (monomictic dacite breccia), and mafic hyaloclastite and autobreccia (monomictic mafic breccia). Other clasts include scoria and pillow fragments. The scoria clasts may be the product of explosive eruption/s or autobrecciation of highly vesicular basaltic lava. Unconsolidated deposits of scoria, pillow breccia and hyaloclastite were easily resedimented to produce the polymictic mafic breccia facies. Syn-eruptive redeposition was probably from density modified grain flows, high-concentration debris flows or turbidity currents. These facies formed thick, laterally discontinuous deposits, infilling pre-existing seafloor topography.

3.16.3 Henty Dyke Swarm

Massive basalt and dolerite dykes have intruded both the Mount Black and Sterling Valley Volcanics. The massive basalts and dolerites have sharp, irregular contacts which suggests that intrusion post-dated lithification. These dykes are correlated with the Henty Dyke Swarm and increase in frequency towards the Henty Fault.

3.17 Summary

Both the Mount Black and Sterling Valley Volcanics include primary, syn-eruptive and post-eruptive volcanic facies. Sparse laminated, black mudstone intercalated with the volcanics facies, abundant hyaloclastite, turbidites and other mass-flow units, and VHMS deposits collectively constrain the depositional setting to below-wave-base.

The Mount Black Volcanics comprise the intercalated products of effusive eruptions, explosive eruptions and post-eruptive resedimentation. They are dominated by feldspar-phyric, massive, flow-banded and brecciated lavas and sills of rhyolitic to dacitic composition. Lavas and sills are composed of massive, originally glassy or crystalline, feldspar- or feldspar-hornblende-phyric rhyolite or dacite that is surrounded by in situ and clast-rotated hyaloclastite and autobreccia. The bases of the lavas and margins of the sills are commonly peperitic.

Variable proportions of pumice breccia, pumice-rich sandstone, shard-rich siltstone, pumice-lithic clast-rich breccia and sandstone and crystal-rich sandstone are intercalated with the lavas and sills. The pumice breccia, pumice-rich sandstone and shard-rich siltstone are the products of large volume explosive eruption/s and were deposited close to the vent from water-supported gravity flows and suspension from the water column. Pumice-lithic clast-rich breccia and sandstone result from the resedimentation of unconsolidated felsic hyaloclastite, autobreccia, and pumice-rich deposits. Pumice clasts were probably derived from a pumiceous carapace associated with rhyolitic lava, a dome-related explosion or redeposition of pumice clasts from unconsolidated pumice breccia. Deposition was probably from gravity flows. Post-eruptive crystal-rich sandstone facies was sourced from extrabasinal

Precambrian basement, other non-volcanic and volcanic facies and from local volcanic sediments. Deposition was probably by high-concentration turbidity currents or sandy debris flows.

Banded and brecciated carbonates facies in the Mount Black Volcanics are interpreted to be the product of sub-seafloor hydrothermal alteration of volcanic facies such as pumice-lithic clast-rich breccia, monomictic rhyolite breccia, rhyolite mixed breccia.

The Mount Black Volcanics represent the proximal facies and intrusive roots of a large felsic submarine volcanic complex. The complex includes widespread ignimbrite-like pumice-rich facies and compositionally related lavas, domes and syn-volcanic intrusions.

The Sterling Valley Volcanics are dominated by dacitic to basaltic lavas and sills composed of variable proportions of coherent and clastic facies. The clastic facies include in situ and clast-rotated hyaloclastite (monomictic mafic breccia) and peperite (mafic mixed breccia). The lavas and intrusions are intercalated with normally graded monomictic mafic breccia, polymictic mafic breccia, mafic volcaniclastic sandstone and siltstone and black mudstone. Graded monomictic mafic breccia is interpreted to be redeposited mafic hyaloclastite. Polymictic mafic breccia, mafic volcanic sandstone and siltstone facies were sourced from local unconsolidated dacitic to basaltic hyaloclastite, autobreccia, pillow breccias and scoria. These syn-eruptive mafic volcaniclastic facies were probably deposited from density-modified grain flows, high-concentration debris flows or turbidity currents. The Sterling Valley Volcanics represent the submarine apron of a large mafic volcanic centre.

Post-eruptive massive basalt and dolerite dykes of the Henty Dyke Swarm have intruded both the Mount Black and Sterling Valley Volcanics.